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PRACTICAL APPROACHES TO

RIPARIAN RESOURCE MANAGEMENT

AN EDUCATIONAL WORKSHOP

May 8-11, 1989
Billings, Montana

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Montana Chapter American Fisheries Society
U.S. Bureau of Land Management
Western Division American Fisheries Society
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Nomenclature Changes. In June 1988, the American Fisheries Society Committee on Names of Fishes decided to change the generic name for all native Pacific-drainage trouts previously called *Salmo* to *Oncorhynchus*. Additionally, the specific name for rainbow trout (and its andromous form, steelhead) was changed to *mykiss*. These changes have been implemented in this publication. Common names of these fishes remain unchanged.

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PREFACE

The idea for this workshop was developed in August 1987, at the Wall Creek Game Range on the banks of the Madison River during the summer meeting of the Montana Chapter of the of the American Fisheries Society. This summer session was a riparian management workshop put on by Lew Myers and Jim Roscoe of the Bureau of Land Management. Wayne Elmore, one of the featured speakers at the workshop, provided the initial inspiration, and we began planning at once. By the end of the 2-day workshop, the steering committee had been selected and site selection and program goals were discussed. This proceeding represents the culmination of those initial plans.

In recent years the riparian zone has become an increasingly important resource consideration; however, literature describing riparian area management has been slow to develop. Although related topics such as habitat typing, nomenclature, and instream habitat enhancement structures are being widely addressed, the "how to manage" literature is not readily available. The primary purpose of this workshop is to bring together practical and successful methodologies in riparian area management and promote and stimulate discussion among a wide variety of interests such as technical specialists, resource planners, managers, and land owners.

The authors of papers included in this book have extended substantial effort in order to complete manuscripts in time to provide each participant in the workshop with a copy of the proceedings for the meeting. The majority of the speakers prepared formal peer-reviewed papers, and the remaining speakers and poster authors have completed extended abstracts. Coeditors Bruce A. Barton and Jeffery L. Kershner worked diligently to assure a quality product, and copy editor Kenneth A. Hashagen, Jr. reviewed each paper for style and format.

Numerous individuals have dedicated their professional careers to riparian management, and their efforts have all contributed to the proper management of riparian resources. We would like to give special recognition for this workshop and publication to Wayne Elmore. His efforts to promote proper use and protection of this valuable resource are an inspiration to all of us. Wayne has been instrumental in establishing effective working relationships with grazing permittees and landowners within the Prineville, Oregon District of the U. S. Bureau of Land Management. He has delivered his message throughout the western USA, and we feel that the greatest tribute to Wayne would be for all to recognize that proper riparian area management is more than the *right* thing to do, it is the *smart* thing to do.

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Selling a Successful Riparian Management Program: a Public Land Manager's Viewpoint

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Abstract.—Management of riparian areas is a key issue facing land managers today. A major challenge for the manager is selling an effective riparian area management program to public land users, interest groups, and private landowners whose holdings are intermingled with public lands throughout the west. A successful program developed in central Oregon during the past 10 years is based upon six major steps: (1) identifying benefits derived from proper riparian management (clean water, more uniform stream flows, less soil erosion, increased livestock forage, and improved wildlife habitat), (2) having access to an "on-the-ground" recovered riparian area accomplished through grazing management, (3) bringing "key players" (affected landowners and permittees, interest group members, agency personnel, and public land managers) together "on-the-ground" to agree on goals, alternatives, and a plan of action, (4) closely monitoring progress in reaching goals, (5) keeping all parties involved and communicating, (6) remaining flexible to changes needed to make the program work. In summary, a strong coalition of land users, landowners, and managers working together on commonly identified goals is the key to selling a successful riparian management program.

The purpose of this paper is to discuss what I feel are the keys to selling a successful riparian area management program, not the technical or scientific keys, but the human relations keys. Much has been, and will continue to be, spoken and written about management strategies, grazing systems, and livestock exclusion to improve riparian ecosystems. However I feel professionals in the natural resources management field have not adequately addressed the most important factor of all, how to work with people (ranchers, wildlife advocates, environmentalists, public land managers and others concerned with proper resource management) to initiate and implement (or, as I prefer to call it, "sell") successful riparian management programs.

The U.S. Bureau of Land Management (BLM) in Oregon and Washington has been acknowledged as a leader in the riparian management field. The Prineville BLM District has been working actively for over 10 years to implement a process of improving public land riparian zones and the associated uplands. Although there is still a large job ahead, the District currently has over 50% of over 650 km of perennial streams in an improving condition.

Several perennial streams in central Oregon have been changed from wide, shallow, algae filled waters to clean, clear, productive streams supporting significant trout populations in 10 years or less. New perennial streams have been created in areas where none has existed for the past 60 to 80 years or longer. Much of this improvement has been accomplished with properly managed livestock grazing.

There are riparian zones in the Prineville BLM District where livestock grazing is not appropriate, such as Camp Creek, with its steep banks and highly erodible soils. However, I feel the vast majority of riparian zones can be significantly improved with properly managed livestock grazing.

Studies have shown that riparian areas can generally be improved by livestock exclusion. However, in my view, riparian exclusion fencing is an unnecessary and expensive alternative that is neither realistic or practical over most of the West. Corridor fencing that protects only the riparian zone also ignores associated uplands, which are crucial to successful management of the watershed.

Studies have documented that most riparian zones can be significantly improved under properly managed grazing. The question is, how to initiate and implement, or more appropriately "sell", a program? The Prineville District staff has identified six key steps involved in "selling" a successful program:

(1.) Identifying benefits or products derived from proper riparian management (clear water, more uniform stream flows, less soil erosion, increased livestock forage, and improved wildlife habitat),

(2.) Having year long access to an "on-the-ground" recovered riparian area that was accomplished with grazing management,

(3.) Bringing key "players" (affected landowners and permittees, interest group members, other agency personnel, and public land managers) together "on-the-ground" to observe the recovered area and to agree on goals, alternatives, and a plan of action for other areas,

(4.) Closely monitoring progress in reaching goals,

(5.) Keeping all parties involved and communicating, and

(6.) Remaining flexible to changes needed to make the program work.

There are undoubtedly other successful management programs, but this is one that has worked for BLM in Prineville. The above steps are listed in the approximate order that we feel they should be implemented. However, there is considerable overlap between most steps and flexibility is essential to successful program implementation.

Identify Riparian Zone Benefits or Products

The first step to "sell" a program is to "identify benefits or products derived from proper riparian management." Riparian zones mean different things to different people. It is essential that the end products of proper riparian management, whether they be economic or aesthetic in nature, are clearly defined.

For many years natural resource managers and scientists tied riparian zone improvement to wildlife because they recognized the benefits of the riparian areas to most species of wildlife and fish. The wildlife and fisheries biologists were among the first champions of improved riparian zones in BLM and other land managing agencies. However, the biologist, the range conservationists, or the manager more often than not encountered serious resistance when trying to sell improved riparian management to ranchers based upon the benefits to fish and wildlife. Most ranchers, although they enjoy seeing wildlife on the land, could see no direct economic benefits from the fish and wildlife; few saw benefits for them in an improved riparian zone. However, improved stream flow, more forage, and reduced soil erosion is another matter. Show a rancher how he or she can have longer periods of stream flow, improved water quality, increased forage production, and reduced erosion of valuable bottom lands, and you significantly increase the odds of that rancher adopting the program.

The land managers in the Prineville District began many years ago selling the riparian area management program to ranchers based upon how it could benefit them, not how it would benefit the angler, hunter, or bird watcher, and it has worked! If riparian area management programs are to be successfully sold to public land users, whether they are ranchers or conservationists, the first job of the land manager is to identify the benefits important to that land user. If this step is done, the "selling" job is greatly simplified. However, if it is not done, the program will be much more difficult to successfully implement and is probably doomed to failure.

Although this essential first step of selling the program based upon benefits to the "buyer" sounds simple, it is not! There are, and always will be doubters and skeptics who will say "I don't believe the program will provide the benefits you claim." This is the point where the second step of "Having year long access to an 'on-the-ground' recovered riparian zone accomplished through grazing management" becomes important.

Have Access to An Improved Riparian Zone

There is nothing more effective in selling riparian management than an area where the benefits and products of proper riparian management (improved stream flow, clean water, increased forage production, and improved wildlife habitat) can be seen, walked upon, touched, and discussed. A demonstration riparian area, improved through grazing management, can do more to "sell" a program than all the rhetoric a land manager can ever deliver to the land users. Location and access to the demonstration area are very important considerations. If there is not a local riparian area improved through grazing management, an area in another region or state may be used. However the local area is always more effective as it will reduce the skepticism that "management may work here, but it won't work in my area." Year long access is also very important for observation of riparian zone functions throughout the year and their relationship to management strategies.

A very important point in the step is to distinguish between demonstration, or "show me", areas accomplished with and without grazing. "No grazing or total exclusion areas" will not sell a riparian area management program to most ranchers, because almost everyone agrees livestock exclusion works for the riparian zone. The exclusion area will provide most benefits, but it is not useful to convince those you need to sell the most. However, riparian exclusion areas adjacent to grazing management areas are good reference points, and they can help to sell properly managed grazing for duplicating natural riparian recovery.

The establishment of grazing management practices that lead to improved riparian zones has, in the past, been to a large degree a process of trial and error. However, with our current knowledge of riparian ecosystems and the physical processes basic to all streams, we are able to accurately predict the success of most management practices prior to field implementation.

Bring "Key Players" Together "On-the-Ground"

It is not absolutely essential that a recovered area be located in the same area where you are attempting to begin a riparian area improvement program. However, having an area in the vicinity helps because it is much easier to move to the third key step to success of "Bringing the 'key players' (affected landowners and grazing permittees, interest group members, other agency personnel, and public land managers) together 'on-the-ground' to observe what can happen and to agree on goals, alternatives, and a plan of action for riparian area management on other areas."

This is an essential step that cannot be eliminated or downplayed in importance. Many programs have failed or been less than fully successful primarily because each of the affected groups has not viewed successful "on-the-ground" management programs and group members have not had the opportunity to interact with the other players. Some feel that this step can be done in an office or classroom, but it is much more effective done on the land while viewing a success story.

Often it is difficult to get different interest group members "on-the-ground" together, but it is essential to successful completion of this step in the process. Only when each of the various interests is represented, is true progress made. An excellent example of such interaction has been demonstrated by the Oregon Watershed Improvement Coalition, a group comprised of leaders from the livestock and forest products industries and several major conservation organizations in Oregon, under sponsorship of the Society for Range Management. This group is pioneering cooperation in watershed management throughout Oregon and is an organization you will undoubtedly hear much more from in the future.

Although some riparian management discussions will involve only the land manager and the rancher, it is essential to the long term success of a program to have the wildlife advocate, environmentalist, and other interested parties involved in the process. Experience has shown that a tremendous amount of synergism occurs from field sessions where all parties are involved. When all are involved, each individual is better able to see and understand the others' viewpoints regarding riparian management and better relate to other land management philosophies. Successful riparian area management programs undoubtedly have been implemented without all interested parties being involved, but the chances of success are much higher with what we call "integrated involvement."

The step of bringing all major interested parties together to discuss and agree on goals, alternatives, and plan of action is a major step and should not be attempted in one session. People need time after an initial meeting to think about what they have seen, heard, and discussed. Many times the participants are far apart (or perceive that they are) in thought processes and philosophies about riparian management. It takes time to sort out exactly where each stands on the riparian issue. Therefore, it is strongly suggested that a series of meetings be planned over a period of months to give those involved adequate time to absorb information and review the alternative. It may take several trips to a successfully managed riparian area for the "key players" to begin to see what has occurred and to integrate the results into their expectations and a proposed plan.

A brief word about goals and alternatives. It is essential that goals be established and well understood by all participants. There would be nothing more frustrating, and possibly fatal, to a program than to learn far down the implementation path that goals were not clearly understood in the beginning. The participants will have different initial goals. For example, the rancher may desire more permanent livestock water, reduced bank erosion, and increased forage production from the riparian zone and the wildlife advocate will likely desire improved habitat for wildlife, greater fish production, cleaner water, and reduced erosion. These goals must be identified and tied to improved ecological condition of the riparian area, an overall goal that can be supported by all participants.

It is also important to explore alternative solutions to resolve land management problems. There are usually several alternatives available and having more than one option improves the chances of finding a solution that is acceptable to the participants.

Monitor Progress

A fourth major step to successful riparian management is to "monitor progress in reaching established goals." All individuals involved in any facet of land management (ranchers, government representatives, or interest group members) know that we must not only develop and implement sound programs, but we must carefully evaluate what is happening on the land and what changes may be necessary to ensure the overall success of a program. It is no different with riparian management. We must monitor progress in reaching the previously established goals for the area.

Successful monitoring begins with establishment of baseline or current resource conditions followed by periodic re-evaluation of the area to compare where we are today with where we were when the program began. This may include a variety of methods to measure vegetation, soil, macroinvertebrates, wildlife and fish populations, water quality and quantity, and other possibly important environmental parameters. I will not discuss specific methods; however, I do want to emphasize one monitoring technique which, in my opinion, is mandatory. The method is permanent photo points along the riparian zone.

General view photographs, taken at permanently marked points, are probably the single most valuable monitoring tool that can be employed to document riparian habitat changes. Photos are quick, easy, and almost fool proof with modern cameras. They can be of more value to document change and to help sell future riparian management programs than any other tool you can employ. Although one must carefully interpret photos, they can and do show dramatic results on improving riparian zones. Photos can be used in presentations, published in journals, magazines, and brochures, and kept in permanent files to document change and to show those who cannot personally visit improved riparian areas the results that can and do occur under improved management.

I suggest, as a minimum, that permanent photo points be established at approximately 400-m intervals on all stream riparian zones. If at all possible, the photo points should be established prior to implementation of improved management programs to show both the before and after story. The 400-m rule is a minimum, and more frequent points can be employed, if desired. Photo points should also be established around lakes, ponds, and reservoirs to show changes.

Involvement and Open Communication

"Continued involvement and open communication" are certainly keys to implementation of successful riparian management programs. Once a program is agreed to and implemented, one cannot assume that the game is over and the riparian zone has won. There are plenty of pitfalls along the road to riparian area recovery. A lack of continued involvement or poor communication among the "key players" is a major obstacle that must be recognized and dealt with if and when it surfaces.

If an improvement program is to be a long term success, those who develop and implement the program must stay involved as it is implemented. Periodic field trips to the area as the riparian zone is recovering are very valuable to all involved parties and will help to maintain interest because something new is observed on almost every trip. Riparian zone recovery is a long term and dynamic ecological succession process. There are always new and exciting events or changes occurring, such as the June 1987 flood event on the Bear Creek riparian management area, south of Prineville. This flood, which caused considerable watershed and property damage outside the improved riparian zone, deposited significant amounts of sediment and resulted in very positive bank building in the area currently under intensive grazing management. Changes such as these must be documented, evaluated, and considered in the overall management plan for the area. We are just beginning to fully understand riparian zone management, and continued involvement by all parties is essential to long-term success.

Maintain Flexibility

"Flexibility" is the last key step to successful riparian area management. All riparian management programs will require some changes to be successful. If a plan is well conceived and implemented, the changes may be minor. Participants should not look upon change as something bad or a sign of failure but should view required changes as a positive part of dynamic riparian management. We still have a tremendous amount to learn about riparian management, and many times we have to experiment to find the best solutions.

The key to managing change in riparian management programs is to maintain flexibility and do not be afraid to try something new if what has previously been tried is not working or meeting management objectives. Prior to making changes, the reason for the change should be thoroughly discussed with all key participants. Thorough discussion improves trust among group members and generally results in identification of the best alternative solutions to the problem at hand.

Summary

I have listed what we in the Prineville BLM organization believe to be six essential key steps to implementing a successful riparian management program. We have used them, and they have worked for us. They are presented to provide to others involved in natural resource management ideas on how to initiate and successfully implement management programs, both in riparian zones and other lands under our stewardship.

The development of a strong coalition of land users, landowners, and managers working together to reach common goals, monitoring results of management actions and keeping communication lines open, are the keys to "selling" and implementing a successful riparian management program. This process leads to a program where everyone comes out a winner, including the riparian zones.

The Oregon Watershed Improvement Coalition's Approach to Riparian Management

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Abstract.—A unique coalition of ranchers, environmentalists, and range specialists, the Oregon Watershed Improvement Coalition (OWIC) is dedicated to improving communications between its member groups and improving riparian ecological conditions in Oregon's rangeland environment. Formed in 1986, the OWIC has developed, through a consensus process, specific objectives to meet its goal of insuring the long term benefits of riparian areas and their associated uplands. To achieve its objectives the Coalition is sponsoring a project in the Bridge Creek Watershed in central Oregon. The purpose of the project is to build and involve a local coalition of land owners in the decision making and site specific problem solving processes, and to demonstrate that changes in management can achieve desired goals in riparian and upland conditions.

The formation of the Oregon Watershed Improvement Coalition (OWIC) was initiated by members of the Pacific Northwest Section of the Society for Range Management (SRM) early in 1986. The intent of the SRM in forming the OWIC was to develop communications among various groups interested in the management of riparian zones in the rangeland environments of Oregon; however, these groups were not necessarily in agreement on how these zones should be managed. Battles fought over resource issues in Oregon have polarized agricultural and environmental interests, seriously hampering efforts to effect solutions. Member organizations include: Oregon Cattlemen's Association, Oregon Forest Industry council, Oregon Trout, Oregon Natural Resources Council, Izaak Walton League of America, Oregon Environmental Council, and the Society for Range Management, PNW section.

Since its formation, OWIC members have combined their diverse interests into a unique working force, one based on collaboration rather than confrontation. By opting to keep the active membership small (15) and networking with other organizations and individuals via a mailing list, the OWIC has created an atmosphere conducive to frank, open discussions of sometimes sensitive and volatile issues. It has been through these discussions that each member has learned to recognize and appreciate a variety of watershed interests that led the group to develop a common goal: to insure the long term benefits of riparian systems by providing information that will help with the improvement of riparian systems and their associated uplands compatible with the varied land use objectives of land owners and managers.

Although the primary focus appears to be on the riparian zones, the approach used in attaining the OWIC goal addresses the condition of the entire watershed. The OWIC recognizes the ecological relationship between the riparian zone and associated uplands. The OWIC hopes to assist in the development of management programs that identify objectives that respond to and are consistent with riparian ecological process operating in a watershed.

The OWIC recognizes that the basic functions of a riparian system are to (1) filter water and trap sediments, (2) provide streambank stability, and (3) store water and recharge underground aquifers. The key to a functioning riparian system is riparian vegetation. All other benefits associated with a healthy riparian system, such as fish and wildlife habitat, livestock forage, and late season flows depend on the proper management of riparian areas. Although the current emphasis concerns livestock use, this concept could be applied to other land use activities such as logging, mining, or recreational development.

The OWIC approach emphasizes changes in management to achieve desired goals. It is based on work done by Elmore and Beschta (1987) on Bear Creek and Winegar (1977) on Camp Creek in central Oregon. In the case of Bear Creek, temporary exclusion and change of grazing season were the tools used to achieve riparian recovery; permanent exclusion was deemed necessary in the case of Camp Creek.

One way to promote a greater understanding of riparian processes and watershed management potentials to private and public interests is through an education program. As a major component of the OWIC education program, the group is sponsoring a watershed demonstration project. The aim of the project is to illustrate how watershed rehabilitation can be achieved by working with the system rather than imposing our will on it.

The Bridge Creek watershed in central Oregon was selected as a demonstration area. Bridge Creek is a tributary of the John Day River in Columbia River basin. It is primarily rangeland; however, the headwaters, located in the Ochoco National Forest, are forested. The watershed includes a mixture of public and private land. Bridge Creek supports a population of steelhead trout *Oncorhynchus mykiss*. Problems in the basin include loss of riparian habitat, gullying, and juniper invasion. The soils are highly erodible, and the area is subject to severe summer storm events.

The OWIC has the support of the federal land managers in the watershed and has identified several interested private land owners. They are currently in the process of defining specific sites in the project area.

Another facet of the educational programs is the production of printed materials that reflect the OWIC philosophy and document progress in watershed recovery. Products to date include an information paper about the OWIC and a brochure entitled "Riparian Areas — Their Benefits and Uses". The riparian brochure has been very well received and is in its third printing. Another brochure focusing on the watershed concept and the relationship between riparian areas and upland areas is on the drawing boards. The OWIC also shares information by distributing meeting minutes to over 200 interested individuals. A library of case histories of riparian restoration projects, a riparian bibliography, and various slide and/or video presentations are also being developed.

The OWIC views its role as that of catalyst and facilitator in bringing together people, resources, and technical knowledge. The concept that is fostered is that of a healthy watershed, with the result that everyone benefits. The OWIC, through its unique membership, can provide the impetus and support for seeking pathways to develop working programs for sound watershed management.

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Cooperative Resource Management on the Muleshoe Ranch Preserve

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Abstract.—The 22,182-hectare Muleshoe Ranch is an historic cattle ranch owned jointly by The Arizona Nature Conservancy, the Bureau of Land Management, and the U. S. Forest Service. One of the best watered areas in southern Arizona, the Muleshoe Ranch supports seven perennial streams and five species of increasingly rare native fishes. Riparian forests and mesic scrublands are home to many bird and plant species considered uncommon in the arid southwest. Riparian and watershed protection and enhancement are among the most important biological management objectives on the Muleshoe Ranch and serve to focus cooperative management activities between the three agencies involved in the project.

Ownership Background

Situated at the southern end of the Galiuro Mountains, the 22,182-hectare Muleshoe Ranch spreads over 233 km^2 of some of the most rugged and empty country in southeastern Arizona. Precipitous canyons and spectacular escarpments frame rolling topography and mesa-like depositional features. Perennial streams course through faulted volcanic terrain where numerous uncommon plant and animal species utilize diverse habitats found along the ecological cline between true Sonoran desert in the lower elevations and coniferous forests along the crest of the Galiuro Mountains.

Identified by the original Arizona Natural Heritage program as one of the most biologically diverse and significant natural areas in southern Arizona, the Muleshoe was targeted as an important site meriting special protection by The Nature Conservancy. One of the largest historic cattle ranches in the region, the Muleshoe Ranch was a complex mosaic of lands owned and administered by four separate agencies: 2,051 hectares of land in private ownership, 1,230 hectares in a U. S. Bureau of Land Management (BLM) grazing allotment, 8,572 hectares in a State of Arizona grazing lease, and 8,940 hectares held in a U. S. Forest Service (USFS) grazing permit. As is common throughout the west, the private landowner managed a grazing operation on the historic ranch lands leased from the state and federal government.

In 1982, after an aggressive, large-scale fundraising campaign, the Arizona Nature Conservancy purchased the Muleshoe Ranch in its entirety, both the private lands and grazing rights to lands leased from the Arizona State Lands Department, BLM, and USFS. In 1984, an additional 442 hectares of private land and 947 hectares of state grazing lease land were added to the original purchase when The Nature Conservancy acquired adjacent property in the Bass Canyon drainage. The Arizona Nature Conservancy, after spending approximately $1.2 million on land acquisition and an additional $1.3 million to establish a management endowment, owned fee title to 2,493 hectares. The Nature Conservancy also held grazing rights on 19,689 hectares of land belonging to the Arizona State Lands Department and the federal government.

Holding 9,519 hectares of Arizona State Trust land offered The Nature Conservancy limited management options on these particular leased tracts. The Arizona State Trust lands are legislatively mandated to generate revenue for the state school system through grazing leases or other means. The State Lands Department is actually bound, by law, to maximize revenues on Trust land. It was recognized by all agencies involved in the Muleshoe project that the Muleshoe Ranch had resource values warranting a management approach less focused on traditional consumptive use and more on the protection and enhancement of wildlife, watershed, and riparian resources. In particular, the protection goals of The Nature Conservancy for the Muleshoe Ranch could best be met with a more flexible, multiple-use approach.

The merit of a multiple-use management approach provided the catalyst for an exchange of property between the Arizona State Lands Department and BLM. The state and federal Muleshoe tracts were included in a state-wide series of land trades between the two agencies. The state-wide land exchanges were designed to consolidate holdings and increase the efficiency of agency management activities. The resulting land trade transferred the state lease lands of The Nature Conservancy into BLM ownership and incorporated the original 9,519 hectares of state land into The Nature Conservancy-held BLM grazing allotment. The land trade allowed BLM and the permittee (The Nature Conservancy) to account for, and manage, multiple-use values under the Federal Land Policy and Management Act (FLPMA) without the State Trust mandate of generating income. After the land trade, The Nature Conservancy co-owned the Muleshoe Ranch with the USFS and BLM; the State of Arizona no longer was part of the multiple-agency management cooperative.

The present ownership status of the Muleshoe Ranch consists of the 8,940-hectare Redfield Allotment in the Coronado National Forest, an irregular mosaic of 2,493 hectares of private fee land, and 10,748 hectares of The Nature Conservancy-held BLM grazing lease land.

Biological Resources

Vegetation

Ranging in elevation from 1,067 m at the bottom of Redfield Canyon to over 2,335 m along the Galiuro crest, the Muleshoe Ranch consists of an interesting array of diverse vegetation associations. Lower, open areas are dominated by Sonoran desert scrub with creosote *Larrea divaricata*, palo verde *Cercidium microphyllum*, saguaro *Carnegia gigantea* and numerous diverse shrubs and grasses. Rolling mid-slopes are vegetated with semi-desert grassland/scrub rich in native perennial grasses and remarkably free from invasive, introduced species. Steeper slopes at mid-and higher elevations support evergreen woodlands of Mexican blue oak *Quercus oblongifolia* and juniper *Juniperus monosperma*. On north-facing slopes an unusual mixed chaparral is dominated by many species typical of Sierra Madrean vegetation common in the mountains of Mexico.

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Seven perennial streams course through the Muleshoe Ranch (Bass, Hot Springs, Double R, Wildcat, Cherry Springs, Redfield, and Swamp Springs creeks), as well as numerous tributary drainages. Several complete watersheds occur within the border of the Muleshoe Ranch. Streamside habitats support broad-leaved, deciduous riparian forests of sycamore *Platanus racemosa* var. *Wrightii*, cottonwood *Populus fremontii*, ash *Fraxinus pennsylvanica*, willow *Salix* spp., walnut *Juglans major*, and Arizona white oak *Quercus arizonica*. Occasional Mexican locust *Robinia neomexicana*, mulberry *Morus microcarpa*, and choke cherry *Prunus virginianus* occur, and dense alder *Alnus oblongifolia* forests line Redfield Creek. Terraces above the modern floodplain are often vegetated with dense mesquite bosques *Prosopis velutina* and interesting mesquite/hackberry woodlands *Celtis reticulata*. Intermittent streams and smaller drainages usually support riparian scrubland associations of seepwillow *Baccharis glutinosa*, deer grass *Muhlenbergia rigens*, and other mesic species.

In addition to diverse upland and riparian habitats found on the Muleshoe Ranch, several sensitive plant species occur, including Arizona alum root *Heuchera glomerulata*, Standley Whitlow wort *Draba standleyi*, Thurber's tithonia *Tithonia thurberi*, and the most robust population in Arizona of the "ball moss" bromeliad *Tillandsia recurvata*.

Wildlife

The diversity of habitats and abundance of water on the Muleshoe Ranch make the area rich in plant, animal, and aquatic species considered unusual in the arid Southwest. Several of the perennial streams are significant in that they support a native fishery that exists without the presence of established introduced species. The native fish assemblage represented on the Muleshoe includes long-fin dace *Agosia chrysogaster*, speckled dace *Rhinichthys osculus*, Sonora sucker *Catostomus insignis*, desert sucker *Catostomus clarki*, and the pool-dwelling Gila chub *Gila intermedia*, a candidate for federal listing as threatened. The Gila chub is known from fewer than 20 sites globally and is considered globally threatened by The Nature Conservancy. Collectively, the streams of the Muleshoe Ranch represent one of the finest remaining riverine aquatic systems in southeastern Arizona.

Streamside corridors provide nesting sites for a host of uncommon bird species, including the rare northern beardless tyrannulet *Camptostoma imberbe* and several majestic raptors: the gray hawk *Buteo nitidus*, common black hawk *Buteogallus anthracinus* and zone-tailed hawk *Buteo albonotatus*. Nearly 200 different bird species have been identified on the Muleshoe Ranch, and during the spring nesting season, brilliantly hued vermillion flycatchers *Pyrocephalus rubinus*, yellow warblers *Dendroica petechia*, and blue grosbeaks *Guiraca caerulea* can be spotted regularly.

Gila monsters *Heloderma suspectum*, desert tortoise *Gopherus agassizi*, black bear *Ursus americanus*, javelina (collared pecary) *Dicotyles tajacu*, mountain lion *Felis concolor*, two species of deer *Odocoileus* spp., and at least four species of rattlesnakes (Crotalidae) range over the Muleshoe country. Peregrine falcons *Falco peregrinus* soar over the rugged rimrock, bighorn sheep *Ovis canadensis* climb on the rough cliffs, and coati *Nasua narica* and ringtail *Bassariscus astutus* forage in dense riparian underbrush. At the biogeographic crossroads between the Sonoran, Chihuahuan, and montane physiographic provinces, the physical attributes of the Muleshoe Ranch provide an unusually diverse assemblage of terrestrial and aquatic habitats for a large variety and concentration of wildlife species.

Cultural Resources

The Muleshoe Ranch region is characterized by a long period of human use and includes material evidence of Mogollon, Hohokam, and Apache cultures. Within the boundaries of the Muleshoe Ranch, lithic and pottery shard scatters are common, and several shelters and pictograph sites have been documented. At least two village encampments have been discovered, a finding which suggests an unusually rich and long-lived cultural history.

The recent chronicles of historic occupation read like the authentic stuff of western lore; outlaws, indians, homesteaders, and gold miners called the old Muleshoe Ranch home at one time or another. First claimed in the early 1870s, the Muleshoe Ranch has had its share of colorful Arizona desert characters. The home ranch, at the historic site of Hooker's Hot Springs, was first an ill-fated health resort, then later the headquarters for a prosperous grazing operation that spanned over 648 km^2 of rugged terrain in southern Arizona.

Near the turn of the century, ranching was temporarily succeeded by mining. The successful, but short-lived, Jackson gold mine is today simply an abandoned shaft that gapes menacingly, and is, along with abandoned homesteads and line camps, silent testimony to bygone days of the western tradition.

Although ranching has been the primary activity on the Muleshoe Ranch for the last 80 years, contemporary recreational use of the public and private lands in the Muleshoe Ranch area is steadily increasing, as backpackers hike the rugged Galiuro Mountains, hunters stalk javelina, and bird-watchers flock to rich birding areas. Academic research is also accelerating on the Muleshoe Ranch. With the recognition of the biotic and physical diversity of the area, many ecological questions are being investigated and answered.

The Cooperative Management Agreement and Future Management Directions

Although the modern boundary of the Muleshoe Ranch essentially follows the margins of one of the most interesting historic cattle ranches in southern Arizona, the mapped border today delimits one of the most unusual cooperative management endeavors in the state. The management partnership between co-owners of the Muleshoe Ranch has many constructive aspects. While still faithful to their diverse management mandates and administrative guidelines, the three cooperating agencies can pool funding and staff talents, focus on riparian and watershed protection, and organize management directives around true multiple-use goals.

In recognizing the unique pattern of land ownership on the Muleshoe Ranch, the agencies agreed to consider the property as a single management unit as much as possible, and thus, develop management activities geared towards furthering cooperative objectives. Management practices on the Muleshoe Ranch have gradually been formalized through a series of agreements that protect the unique biotic and cultural resources on the property while remaining within the regulatory statutes of each cooperating agency.

U. S. Forest Service

The 8,940-hectare Redfield grazing allotment on USFS lands was reevaluated during the Coronado National Forest planning process in 1985 and 1986. With the consent of the permittee (The Nature Conservancy), forest officials, for a variety of economic and ecological reasons, discontinued grazing in this important watershed area. The rugged allotment, most of which is within the Galiuro Wilderness, has no internal roads, few trails, and scarce, poorly maintained fences and water developments. Acknowledging the importance of stable watershed and riparian areas in their Coronado National Forest Plan, the U. S. Forest Service retired the Redfield Allotment, effectively removing grazing as an acceptable land use on that portion of the forest. Because there were no marketable timber resources on the Redfield Allotment and the cattle stocking rate was 1 animal per 44.5 hectares, retiring the grazing option made economic sense and furthered the goals of the cooperating agencies.

After spending over $250,000 for the grazing lease and the right to graze cattle on the Redfield Allotment, The Nature Conservancy had no legal connection to their expensively acquired forest forage lands. The Nature Conservancy interest in the Redfield portion of the Muleshoe was not forgotten; the conservation organization initiated a formal three-way cooperative management agreement between the three agencies involved in the Muleshoe Ranch project. The agreement established policies and procedures for cooperative management activities throughout the entire Muleshoe Ranch.

The Cooperative Management Agreement

With the tacit understanding that The Nature Conservancy was interested primarily in the protection and enhancement of riparian and watershed resources, the BLM, USFS, and The Nature Conservancy negotiated a cooperative management agreement that supports common objectives and interests, identifies the statutory requirements of each agency, and strengthens management coordination on the "Muleshoe Cooperative Management Area". The agreement in no way alters the authority of the USFS or BLM to manage the national forest or public lands within the Muleshoe according to their respective national policies. The cooperative management agreement commits the three groups to working together for the establishment of cooperative management goals and procedures that fulfill their stated objectives: riparian protection for The Nature Conservancy, riparian and watershed stability for USFS, and multiple use management under FLPMA for BLM.

In early 1988, the three groups signed the final cooperative management document that outlines a unique agreement to collaborate on a variety of resource and recreation management endeavors. The three agencies will focus on the protection and enhancement of crucial aquatic, riparian, and watershed habitats, and share concerns for candidate federal threatened species, state listed threatened species, cultural resources, wildlife, recreation, and scenic values. Cooperative projects will include fencing, range trend surveys, prescribed burning, hydrologic and biological monitoring, emergency tactics coordination, research, archeological inventories, signing, and computerized data base development.

BLM

During 1988 and 1989, the Safford District of the BLM will develop a Resource Management Plan (RMP) addressing management objectives and formalizing management directions within the Safford District, an area that includes the Muleshoe Cooperative Management Area. Within the binding context of the three-agency cooperative management agreement, the BLM has several management options to consider on the Muleshoe Ranch, including establishing the public lands as an Area of Critical Environmental Concern (ACEC), and a proposal advocated by local wilderness spokesmen to create wilderness lands in the core of the rugged cooperatively managed project. Grazing portions of the historic Muleshoe Ranch is a viable consideration. During the RMP scoping and planning process, the BLM has granted their lessee, The Nature Conservancy, a 5-year grazing use waiver. The BLM will decide on management strategies for the Muleshoe project only after thoroughly inventorying the Muleshoe Ranch lands acquired from the State of Arizona during the state-wide land exchanges and assessing the multiple use values present in the area.

Under FLPMA, the BLM is mandated to consider multiple use resources on the Muleshoe Ranch, especially valuable riparian corridors and critical watershed regions. On the Muleshoe Ranch, because the three cooperating groups recognize and are willing to manage for unique biotic and cultural resources, the agencies can institute and formalize policies that protect the unique features of the area in such a way that all groups continue to meet specific stated objectives while participating in joint management of the Muleshoe area.

Truly a progressive arrangement, the cooperative ownership and management of the Muleshoe Ranch is an interesting experiment destined to serve as a pragmatic model applicable to the management of unique natural landscapes. Cooperation, communication, and negotiation between The Nature Conservancy and the Safford District of the Coronado National Forest and BLM have been responsible for the success of the Muleshoe Ranch project.

A New Approach to Riparian Management in Washington State

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Abstract.—The 1974 State Forest Practices Act regulates forest practices on state and private forest lands in Washington to protect public resources and maintain a viable timber industry. As successive revisions of the regulations were adopted, new conflicts between the industry, tribes, environmentalists, and state agencies arose. When riparian management regulations were proposed in 1986, rampant controversy erupted. Industry representatives claimed economic bankruptcy; fish and wildlife advocates called the proposals inadequate. As a result, several individuals sought to improve forest practices regulation, especially riparian area management. With the assistance of a non-profit corporation, representatives of all interests were brought into a negotiating forum. After 4 months of intensive effort, agreement was reached that had unanimous endorsement. The Timber, Fish, and Wildlife Agreement (TFW) is noteworthy not only for the unique way it was accomplished but also for the results achieved. Riparian management requirements with increased resource protection were established. The new approach gives flexibility to loggers and still achieves resource protection. The TFW Agreement incorporates framework and procedures that will assure the regulations remain current.

There are about 7.1 million hectares of commercial forest land in Washington (Larson and Wadsworth 1982), which form the basis of one of Washington's largest industries. Over 50% of the state is considered forest land. Commercially valuable fir (*Abies* spp.), hemlock (*Tsuga heterophylla*), and spruce (*Picca* spp.) forests cover most of western Washington and the Cascade Mountains. The northeast and southeast corners of the state contain important pine (*Pinus* spp.) and larch forests.

In 1984, the forest products industry contributed $6.6 billion (or 4.6%) to Washington's gross business income (WDNR 1987). Furthermore, revenues derived from logging on state lands are major sources of monies for schools and county governments (WOFM 1987). The economy of many communities depends upon local forests.

Washington forest lands also support significant populations of economically important fish and wildlife resources. For example, the average annual commercial catch of Pacific salmon *Oncorhynchus* spp. in Washington is 20,000 tonnes valued at $85,000,000 (Ward and Hoines 1986). The value of the recreational fishery for some salmon species exceeds the commercial value (IGF Technology 1988). Wildlife and other fish species in forests are also important recreationally. Virtually all of the salmon resource of Washington is produced in streams within or downstream of forest lands where forest practices have a significant impact.

In Washington forests, riparian habitats are used by wildlife more extensively than any other habitat type (Thomas et al. 1979, Oakley et al. 1985). Of the 480 species of terrestrial and shoreline wildlife, 291 are regularly found in riparian ecosystems. A total of 68 species of mammals, birds, amphibians and reptiles require riparian ecosystems to satisfy a vital habitat need during all or part of each year. At least 22 species of birds are specifically oriented to the aquatic component of the riparian ecosystem. In relation to their size, riparian areas within the forests are disproportionately important to salmon and over 70 other freshwater and esturine fishes. Clearly, Washington fish and wildlife resources depend upon aquatic environments.

Unfortunately, forest practices can destroy fragile fish and wildlife habitat, thereby jeopardizing their continued existence. Consequently, regulation of forest practices in Washington has been replete with conflict and costly litigation that yielded little overall benefit to the timber industry and virtually no protection for habitat. This paper describes the history of forest practice regulation in Washington State, a negotiation process that led to a new approach to regulation, and the results of those negotiations as they relate to riparian management.

Regulation of Forest Practices in Washington

The first forest practice regulation for state and privately owned forest land in Washington was passed in 1946 and pertained exclusively to reforestation. In 1974, the Washington State Forest Practices Act (FPA; Chapter 76.09, Revised Code of Washington (RCW)) established a comprehensive, statewide system for regulating all forest practices on the 4.5 million hectares of state and privately owned land in the state. The intent of the FPA was to foster a sustained forest industry for the state while protecting fisheries, wildlife, water quantity and quality, air quality, recreation, and scenic beauty.

As a result of the 1974 FPA, the Forest Practice Board (Board) was created as an agency of state government and composed of representatives of state agencies, county governments, industry, and general public. The Board was charged with promulgating administrative regulations establishing minimum standards for forest practices. Several technical committees and an advisory body were designated to assist the Board.

Administrative rules adopted by the Board are administered and enforced on private lands by the Washington State Department of Natural Resources (WDNR). The WDNR also has the responsibility for managing most state owned forest lands and must meet or exceed Board regulations in their own forest practices.

Other state agencies are also involved with forest practice regulation. The Washington Department of Fisheries (WDF) manages food fish and shellfish resources of the state and their habitat. Likewise, the Washington Department of Wildlife (WDW) manages the state's wildlife resources and game fish species. The Department of Ecology (DOE) is responsible for management of water quality and quantity.

Administrative regulations to implement the FPA were first adopted by the Board in 1976; water quality was the principal concern. Water temperature increases and streambank stability were the emphasis of the regulations.

Unfortunately, the 1976 regulations did not adequately address riparian areas in forest lands despite their importance for fish and wildlife habitat. All trees could be removed from the riparian area of a stream, sparing only the understory on "temperature-sensitive" streams, which were defined in relation to stream size, orientation of flow, and altitude. On larger temperature-sensitive streams, all shade-providing nonmerchantable vegetation and, if necessary, sufficient merchantable vegetation to provide 50% of the summer midday shade to the water surface had to be left. For streams where high water temperature was documented, 75% of the shade had to be retained. In practice, virtually all merchantable trees could be removed because few streams qualified as temperature sensitive. In addition, provisions were difficult to administer and even more difficult to enforce for a variety of reasons. No consideration was given to wildlife habitat needs or to fish habitat needs other than water temperature.

In 1977 and 1982, regulations were amended by the Board. Attempts to adopt meaningful riparian management considerations were unsuccessful.

In 1984, the Board began reviewing proposals to protect the more than 39,000 km of riparian area and to address cumulative effects of forest practices. Formal regulations were proposed for spring 1986; therefore, the Board directed WDNR to develop an Environmental Impact Statement (EIS) as required by the State Environmental Policy Act (SEPA; Chapter 43.21C RCW). As with previous regulation changes, these proposed rules sparked new controversy. Industry representatives felt the proposals were too strict; fish and wildlife advocates called the proposals inadequate.

Negotiating Process

Dissatisfaction with the proposed regulations was not the only problem encountered in 1986. All interests were dissatisfied with the process for developing regulations. Environmental interests felt that most Board members represented the industry point of view. No members representing environmental interests were specifically designated to balance the industry representatives. The WDF and WDW, despite interest, expertise, and overlapping legal authority, were not represented, and yet a state agency whose interest is jobs and community stability was.

Industry leaders were uncomfortable with having the Board promulgate regulations because of lack of predictability in Board actions. Industry representatives feared that state Indian tribes with treaty fishing rights might seek greater environmental protection through litigation. Small woodlot owners (more than 40,000) feared regulations would be so stringent they would have to convert their land to other uses. Environmental interests shared this fear as alternate land uses would likely be more harmful than proper woodlot management. Hence, most felt that those with a keen interest and knowledge of the affected resources were better suited to devise regulations that afforded an equitable balance of resource use and protection.

Consequently, representatives of several involved parties sought a better way to address forest practice regulations. They approached the Northwest Renewable Resources Center (NRRC) for assistance. NRRC is a Seattle-based nonprofit corporation created in 1984 by corporate, environmental, and tribal leaders to assist in resolving conflicts over the use, management, and conservation of natural resources.

The NRRC agreed to facilitate negotiations to resolve the forest practice regulatory dispute. In late July 1986, the NRRC convened a 2.5-d meeting of over 40 state agency directors, Indian tribe chairpersons, corporate executives, environmental leaders, and their technical representatives, to determine if negotiation was feasible. Throughout the meeting, each interest had ample time to present its views and decisions were reached by consensus opinion. Most importantly, posturing and advocacy were set aside.

Goals and needs of each resource interest were prepared and discussed. As a result, the participants found a surprising amount of agreement in principle among them on many issues. All parties agreed that there was a real opportunity to negotiate forest practice regulations in lieu of those being considered by the Board. "Timber, Fish, and Wildlife" or "TFW" was adopted by the group as the name of the negotiating process and the resulting agreement.

The TFW participants aimed to reach an agreement by November to precede pending forest practice revisions scheduled for December 1986 by the Board. This meant they only had 4 months to resolve issues so complicated that 1 to 2 years would have been a more reasonable time frame. Thus, negotiations began with continued coordination by NRRC.

The TFW participants formed two primary groups: The Working Group, with technical experts, and The Policy Group, or decision makers. The Working Group was organized into committees to address each of the major contentious issues that were essential to an agreement: roads, riparian management, upland management areas, unstable slopes, timber harvest, silviculture, archeological/cultural, old growth, cumulative effects, corrective action, and incentives/compensation. Representatives from each interest and academic experts were included on each committee.

The committees approached the major issues by defining the problems, developing several options, and selecting a preferred alternative. Throughout the process, consensus continued to be the operating guideline. Particularly difficult problems were taken by the committees to the Working Group for discussion and guidance.

In August, the participants reported their progress to the Board, who supported the negotiation efforts and agreed to consider a TFW Agreement as a new approach. The TFW Policy Group retained their November deadline in order to maintain the momentum they had achieved. The committees and the Working Group worked feverishly to develop final recommendations for the Policy Group.

The Policy Group met in early December, and after many long and tedious hours of discussion and negotiation, an Agreement in Principle was reached that the Board reviewed and accepted. The TFW participants continued to meet to resolve agreement details; final agreement was reached prior to January 1987.

Formalization of the Agreement

A set of administrative rules that reflected the TFW Agreement was developed by WDNR, and an Environmental Impact Statement (EIS) was drafted. The proposed rules and the EIS went through the required review process. Public hearings on the proposed rules were held throughout the state. In September 1987, the Board adopted the proposed rules with an effective date of 1 January 1988.

To implement the TFW Agreement, the Forest Practices Act was amended by the Washington State Legislature in 1987. At the same time, the Legislature was also asked to support additional costs for state agencies administering the TFW Agreement; $4.5 million was appropriated for the 1987-1989 biennium. This appropriation was granted during a tight fiscal situation and exemplified the legislative leaders' and Governor's unwavering support of the TFW process.

TFW Agreement

Overview

The TFW Agreement of 1987 marks an historic shift in the management of forest-based natural resources in Washington. The agreement describes an innovative multi-resource management approach that provides the framework and procedures for more effective management of timber, fish, wildlife, and water in Washington. Virtually all aspects of forest management are addressed. The approach provides mechanisms to meet the needs of all interests and protect the state's public resources through integrative solutions to complex environmental management problems. The 54-page TFW Agreement is a detailed document consisting of administrative rules, cooperative/voluntary aspects and adaptive management. These components are discussed as they relate to riparian area management.

Administrative Rules

Administrative rules were devised to accommodate the needs of all interests by balancing resource use and protection. The rules provide three methods that a forest landowner can use in riparian areas. Specific regulatory requirements for virtually all aspects of forest management were adopted in the administrative rules. These regulations provide for a much greater level of natural resources protection in riparian areas then did prior regulations. The rules also provide two ways for a forest owner to deviate from the specific requirements if all parties agree that resource protection equivalent to that which would be achieved by strict adherence to the regulations would still result. The goal is to provide for protection of fish and wildlife habitat, including water quality, while allowing reduced levels of forest management activities under controlled operating conditions.

Regulatory method.—If the regulatory method is chosen, the established base-line regulations apply. A riparian management zone (RMZ) is required. The RMZ widths vary, depending on stream width, fish usage, and other physical parameters. The RMZ includes areas of transitional terrestrial environments bordering streams, lakes, ponds, tidewaters, and other bodies of water. It also includes banks, beaches, and associated organic and inorganic constituents; floodplains; and areas of high water table associated with plants that require saturated soils during all or part of the year. In addition, the RMZ includes areas of direct influence that shape the physical structure of the aquatic environment and affect the quality of fish and wildlife habitat by contributing organic debris, shade, and buffering action.

Specific regulations address RMZ width, application of pesticides along channels, reforestation, road location, slash removal, trees, snags and down logs to be left for fish and wildlife habitat, timber felling methods, yarding, slash fires, and streambank stability. Owners of small amounts of forest land are provided lesser standards for harvest areas of less than 12.1 hectares.

Site-specific method.—With this method, the landowner can propose to deviate from the specific regulations. This provides the latitude to adapt to unique circumstances of the area. The end result, however, must be the same level of fish and wildlife habitat protection as would be afforded by the regulations. Technical personnel from the four state agencies and pertinent Indian tribes are available to consult with the landowner to develop his proposal. Upon proposal completion, agency staff review and/or modify it on-site with the landowner to ensure appropriate public resource protection.

The landowner may present any proposal that accommodates habitat protection. In practice, proposals violate the regulations in one area but exceed them in another. For example, more trees may be removed from one portion of the RMZ while leaving additional trees elsewhere. If the heavier logged area is on the north side of a stream, the stream may actually benefit from the greater shading on the south side during the summer. Another example of flexibility is that the operator may need to locate a road in part of the RMZ to avoid more costly construction costs on a steep slope. To compensate, he may establish a wider riparian area with more unharvested trees in an adjacent area. Fish and wildlife habitat protection and landowner concerns are both accommodated.

Resource Management Planning.—This method of forest practices in riparian areas is strongly encouraged by the TFW Agreement. Under this process, TFW participants and major landowners in a planning unit, usually a watershed, jointly construct a long term management plan for the unit. Specific requirements exist for the process and contents of the plan that may include adaptation of forest practice regulations to meet local needs and requirements for all interests.

Cooperative/Voluntary Aspects

The cooperative, non-regulatory portion of the agreement describes a multi-resource management approach to resource use and protection. Briefly, this calls for forest landowners including WDNR, to: (1) prepare annual plans for timber harvest and other management activities for review by interest parties, (2) voluntarily leave 0.8-hectare "upland management areas" for wildlife, (3) retain state-owned old growth forests wherever possible, (4) develop long term management plans, and (5) inventory abandoned roads to alleviate erosion. These voluntary aspects exemplify the cooperative spirit and attitude that prompted participation and allowed development of the TFW agreement.

Adaptive Management

The third and most dynamic component of the TFW Agreement is adaptive management, a policy implementation and planning approach to address uncertainties in managing natural resources. More simply, adaptive management is a trial-and-error process that uses monitoring, research, and evaluation to determine the results of regulatory actions.

Important gaps in knowledge of the effects of forest practices regulations on fish, wildlife, and their habitat have been identified by TFW participants, and studies have been outlined to address them. Agreement has also been reached on needs for monitoring and evaluating the effects of existing regulations. Monitoring and research results will be utilized to modify regulations and improve habitat protection and effects on timber management.

The TFW agreement calls for annual review, with special third- and eighth-year requirements. The annual review will be an assessment by representatives of the parties of how the formal and informal portions of the Agreement are meeting their needs. At the end of 3 years the participants will conduct an in-depth evaluation of the impacts of the TFW Agreement on public resources and timber operations. If changes to the regulations are felt to be necessary, proposed changes will be presented to the Board.

At the end of the 8 years, the participants will conduct a comprehensive evaluation of the entire Agreement and present their conclusions to the Board. At that time it will be determined if the Agreement is to remain unchanged, be renegotiated, or abandoned.

The adaptive management aspects of TFW provide the framework to update the Agreement and ensure successful use and protection of the timber, fish, wildlife, and water resources of Washington forests.

Eastern Washington Riparian Management Zone Regulations: TFW's First Adaptive Management Success

Eastern and western Washington differ in topography, elevation, climate, streams, forests, and other aspects. Adopted riparian regulations were primarily established to meet the conditions in western Washington.

Modification of riparian regulations to accommodate the unique features of eastern Washington were the first forest practices rules developed using the adaptive management approach. Description of the process of developing these regulations exemplifies the adaptive management process.

The TFW participants formed the Eastside Riparian Committee (ERC), which consisted of 20 individuals representing WDNR, DOE, WDF, WDW, forest industry, Indian tribes, and environmental groups. The ERC charge was: (1) develop RMZ regulations that effectively protect public resources, (2) consistent with this resource protection, provide for maximum timber harvest, and (3) develop the geographic boundary for applying these regulations.

The ERC formed four survey teams to inventory RMZ characteristics on 72 streams. These teams focused their efforts in four geographic areas to facilitate data collection and determine if regional differences in RMZ areas existed. Data were collected on the frequency and character of large organic debris (LOD) within the stream channel and vegetation characteristics (tree densities, diameters, heights, age, canopy closure, and herbaceous and shrub cover) from each bank to a distance equal to the height of the potential LOD recruitment. All data collection and analyses were done by TFW participants between August and December 1987. These cooperative efforts required the equivalent of 1½ person years at an estimated cost of $110,000.

From January to March 1988, the ERC developed proposed regulations based on their findings and results from other studies. The Board subsequently adopted the proposed regulations after developing a supplemented EIS and going through the required public review process.

These regulations reflect the ERC study results and the views of the public (Appendix). More importantly, they exemplify commitment by the participants to make the TFW Agreement work to successfully manage the natural resources on Washington forest lands. The complete TFW Agreement and forest practices administrative rules may be acquired from the Washington Department of Natural Resources, Olympia, Washington 98504.

Acknowledgments

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Appendix

Western Washington

1. A RMZ shall be established with the width depending on size of stream and fish usage. Minimum width on streams with significant fish usage is 7.6 m. Maximum width that can be required is 30.5 m.
2. Pesticides shall not be applied aerially within 15.2 m of a stream.
3. Reforestation will be accomplished to specified standards within 3 years.
4. Roads are generally precluded except for crossings.
5. Slash removal shall occur under specific guidelines.
6. Slash disposal, site preparation, and application of chemicals will be conducted by hand.
7. For wildlife habitat, snags and down logs will be protected, and an average of 12.3 conifer or deciduous trees per hectare. Trees must be representative of the stand.
8. Along larger streams with significant fish populations, additional representative trees must be left for fish and wildlife habitat depending on the characteristics of the stream. For streams 22.8 m or greater in width, up to 50 randomly distributed conifer and deciduous trees per 305 m must be left on each side that is logged.
9. Specific felling requirements protect vegetation to be left.
10. Removal of logs and debris is restricted to minimize habitat damage.
11. Yarding will be conducted in a manner to minimize damage.
12. Slash fires must be kept out.

13. Road construction spoils must be placed above the 50-year flood level.

14. Specific requirements are established for maintaining streambank stability.

Eastern Washington

1. RMZ width requirements are based on harvest types. Partial cuts require a minimum of 9.1 m on each side of the stream; regeneration cuts require an average width of 15.2 m with a minimum of 9.1 m on each side of the stream.

2. Requirements are established for trees that must be left unharvested within the RMZ to ensure snag retention and recruitment for cavity nesters, canopy closure, and to retain vertical diversity. To accomplish these objectives the following must be left:

a. All trees 4.7 cm or less diameter breast height (dbh)

b. All snags within the RMZ that follow State Department of Labor and Industries safety regulations.

c. At least 40 representative live conifer trees per hectare between 4.7 - 7.8 cm dbh.

d. Seven conifer trees 7.9 cm or greater dbh and the five largest live deciduous tree per hectare 6.3 cm or larger. If these deciduous trees and five snags 7.9 cm or larger are nonexistent, substitute five conifers 7.9 cm dbh or larger; if live 7.9 cm dbh or greater are nonexistent, substitute the 12 largest live conifer trees and leave 7 live deciduous trees between 4.7 - 6.3 cm dbh where they exist.

3. Additional leave tree requirements apply to ensure LOD recruitment and benefit canopy cover, snag, and snag recruitment. The minimum leave tree requirements per hectare as they pertain to streambed composition are:

> Boulder/bedrock streams — 185 trees 1.6 cm dbh or larger. Gravel streams — 334 trees 1.6 cm dbh or larger. Pond and lakes — 185 trees 1.6 cm dbh or larger.

4. Standards similar to those for western Washington are established for pesticide and chemical use; reforestation; road construction; slash removal and fires; timber felling and yarding; and streambank stability.

Integration of Riparian Data in a Geographic Information System

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Abstract.—A geographic information system (GIS) offers the opportunity to integrate stream resource information at the watershed scale. A case study using several information layers and their use in developing a stream enhancement project is presented. The GIS map and information bases for Cummins Creek, Oregon Coast Range, include geomorphic stream reaches, stand conditions, plant associations, large woody debris survey, and the stream network. Integration of these data bases allows analysis of the distribution of large woody debris, potential input of woody debris from riparian stands, and the location of areas most suitable for silvicultural treatment to increase the representation of decay-resistant large wood in riparian stands. Other kinds of analyses and models are possible using this information, including debris torrent potential, cumulative effects, and stream habitat evaluation and monitoring.

Complex physical and biological landscape features come together in riparian ecosystems. Interaction of these features gives rise to an array of ecosystem properties and functions and complicates management decisions. At the very least, riparian management must consider fish and wildlife habitat, vegetation, sediments, and water resources. The stream network, hydrologic features, climate, drainage basin geography, geologic conditions, geomorphic features, existing vegetation, potential vegetation or seral development paths, and topography drive the development of fish and wildlife habitat, production and quality of water and other ecosystem processes as well as the spectrum of human uses.

One way to begin to understand the complexity of riparian ecosystems is to separate the basic physical and biological elements of the ecosystem into discrete data sets and examine interactions through combinations of these in models. The existence of advanced geographic information systems (GIS) facilitates the development of map coverages of these data sets and models for particular applications. A GIS allows the storage and manipulation of map information and data associated with map features. Map layers can depict various kinds of information including stream networks, stand conditions, geomorphology, topography, watersheds, and transportation systems. Types of analyses possible include simple overlays, generation of topographic features, buffer generation, and network flows.

This project was designed to take advantage of existing GIS resource maps on the Siuslaw National Forest. Additional information on valley floor morphology and large woody debris from a stream survey was combined with the existing GIS maps to design stream enhancement projects. The initial focus was to design stream buffers incorporating valley floor morphology, depict potential inputs of woody debris to the stream from riparian stands, and highlight areas deficient in large woody debris where silvicultural manipulations of riparian stands would be cost-effective. Cummins Creek was chosen as a demonstration area because of available GIS map layers and stream survey.

Study Area

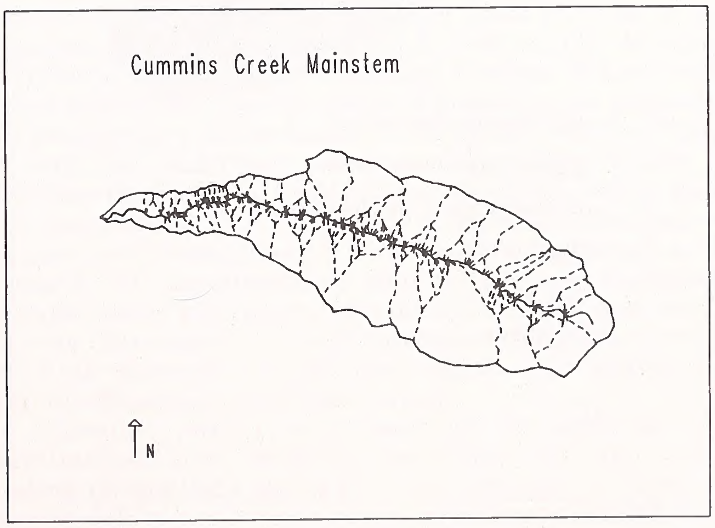
Cummins Creek empties directly into the Pacific Ocean 18 km south of Waldport, Oregon. The 2,150-hectare watershed drains an area of intrusive basalt headlands on the Siuslaw National Forest. The topography is relatively steep and moderately dissected with elevations ranging from sea level to 760 m. The mainstem is 11.5 km long. Stream gradient ranges from 1% to 2% at the mouth to over 10% near the head wall source. Most tributary basins are short, steep, and nearly perpendicular to the mainstem. Tributary basins in the lower portion of the watershed are generally small (Figure 1). Several major tributary basins enter near the head of the mainstem.

Valley walls rise quickly from the flood plain. Debris torrents have swept into the mainstem at most tributary junctions in the past several hundred years, leaving deposits of cobbles, boulders, and large woody debris. Resulting debris deposits often form structures that are heavily used by fish for both spawning and rearing. There are several areas of large, deep-seated earth flows at the upper end of the basin.

The climate is maritime, with wet, cool winters and relatively dry, mild summers. Most of the precipitation falls in winter rain storms. Total precipitation ranges from 31.5 cm in the low-lands to well over 39.4 cm near ridge tops (Hemstrom and Logan 1986).

The watershed is heavily forested. Pure and mixed stands of Douglas-fir *Pseudotsuga menziesii*, Sitka spruce *Picea sitchensis*, western hemlock *Tsuga heterophylla*, red alder *Alnus rubra*, and bigleaf maple *Acer macrophyllum*

Figure 1.—Stream network and sub-basins in the Cummins Creek watershed. The stream drains from right to left directly into the Pacific Ocean.



dominate the vegetation throughout the drainage (Figure 2). Most existing stands originated following a series of wildfires about 120 years ago. Salmonberry *Rubus spectabilis* plant associations (Hemstrom and Logan 1985) dominate the most moist sites, including riparian areas (Figure 3). Swordfern *Polystichum munitum* associations form the understory vegetation on moist but well-drained middle slopes. Salal *Gaulteria shallon* associations dominate the driest ridge tops.

Three species of salmonids reproduce naturally in the clean, cool water, including cutthroat trout *Oncorhynchus clarkii*, steelhead trout *O. mykiss*, and coho salmon *O. kisutch*. Elk *Cervus elaphus*, deer *Odocoileus hemionus*, and black bear *Ursus americanus* are common in both the riparian and upland portions of the watershed. Beaver *Castor canadensis* and other riparian mammals are abundant in some locations.

The Cummins Creek watershed was designated as a Wilderness Area by Congress in 1984. Relatively minor amounts of timber harvest had occurred in the watershed prior to that, with the exception of a large block of private land harvested in the middle 1970s. Roads have been closed, and the area will revert to natural conditions over time. The watershed lies immediately adjacent to some intensively managed forest lands where the conflicts between uses and the impacts of clearcut timber harvest and road building are critical issues. A considerable amount of research has taken place on fish populations and fish habitats in the watershed during the past decade. The area serves as a relatively pristine example of habitat when compared to adjacent heavily impacted ecosystems. It is a good place to examine the relationships of biological and physical landscape features in a natural landscape and model the impacts that might occur on similar intensively managed lands.

Figure 2.—Current forest stand conditions in the Cummins Creek watershed.

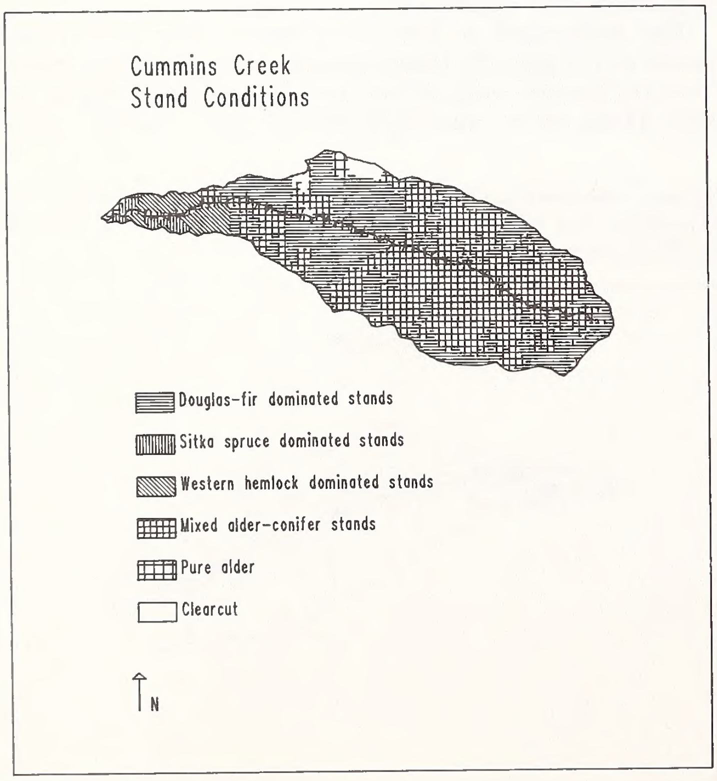
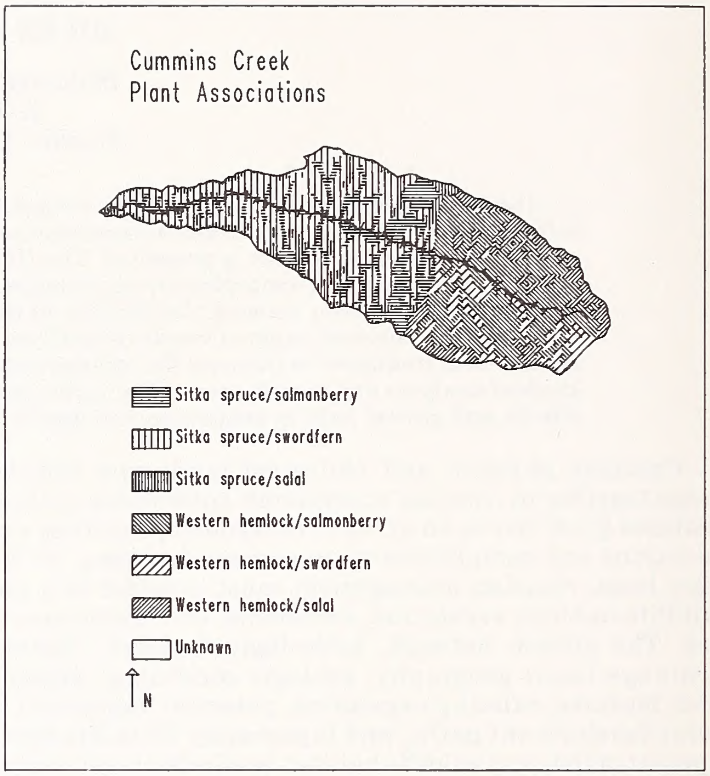

Cummins Creek
Stand Conditions
Douglas-fir dominated stands
Sitka spruce dominated stands
Western hemlock dominated stands
Mixed alder-conifer stands
Pure alder
Clearcut
N

Figure 3.—Plant associations in the Cummins Creek watershed.



Methods

Several kinds of information were available from existing Siuslaw National Forest GIS map coverages. Efforts to collect basic resource information have been underway for several years, resulting in coverage of the entire Forest by maps of plant association groups, current stand conditions, digital elevation data, ownership, transportation systems, and other information. For this project, coverages of plant association groups and current stand conditions were most useful.

Valley floor morphology and other riparian attributes were surveyed along the mainstem of Cummins Creek in the summer of 1987 and converted to GIS format. Stream reaches, the smallest pieces of the stream network mapped in the GIS, were defined by the geomorphic process that impose constraints on channel movement (Grant 1986; Vest 1988). Constraining features were more than 2 m above normal high water level by definition. Data collected during field mapping of valley floor morphology included constraint type, active channel width, valley floor width, vegetative canopy cover, substrate information, proportion of pools and riffle, large woody debris per 100 m of channel, and evidence of wildlife use. For the most part, the Cummins Creek channel is constrained by small alluvial fans or is unconstrained. Inactive earth flows converge on the channel from both sides in a small portion of the upper watershed.

Buffer Generation

Knowledge of valley floor morphology can be very useful in riparian analysis (Sullivan et al. 1987; Swanson et al. 1987). The geomorphology of the valley floor sets in motion long-term processes that strongly influence stream channel conditions and the kinds and degree of interaction between the terrestrial and aquatic ecosystems. For example, a deep-seated earth flow encroaching on a stream channel generally pushes the stream against the opposite valley wall, accelerating erosion, and delivers large boulders to the channel that are not moved by normal high flows. This situation frequently results in boulder cascade channel morphology (Grant 1986) and a relatively narrow zone of contact between the terrestrial and aquatic ecosystem. In contrast, a stream meandering through a wide, unconstrained valley floor often forms open, gravelly reaches. Under these conditions, the stream interacts extensively with the adjacent terrestrial system via bank cutting during high flows and input of coarse woody debris, leaves, and other energy sources. In-stream production, including fish, under these conditions is often high (Reeves et al. 1987).

Existing Siuslaw National Forest timber management practices leave vegetation to protect the stream from excessive increases in water temperature or sedimentation and to provide large woody debris. The exact widths of stream side buffers are often difficult to prescribe, except that they must meet standards set forth in the State of Oregon Forest Practices Act and the National Forest Management Act. As a consequence, riparian buffers are often arbitrarily 33 m wide. The ambiguity involved in defining buffer width is, in part, produced by a lack of clear understanding of the relationship between terrestrial and aquatic ecosystems. Much of the interaction is a function of valley floor morphology (Swanson et al. 1987). Geomorphic constraints, such as landslides and bedrock gorges, and wide, unconstrained valleys determine the long-term kinds and degree of interaction between aquatic and terrestrial ecosystems.

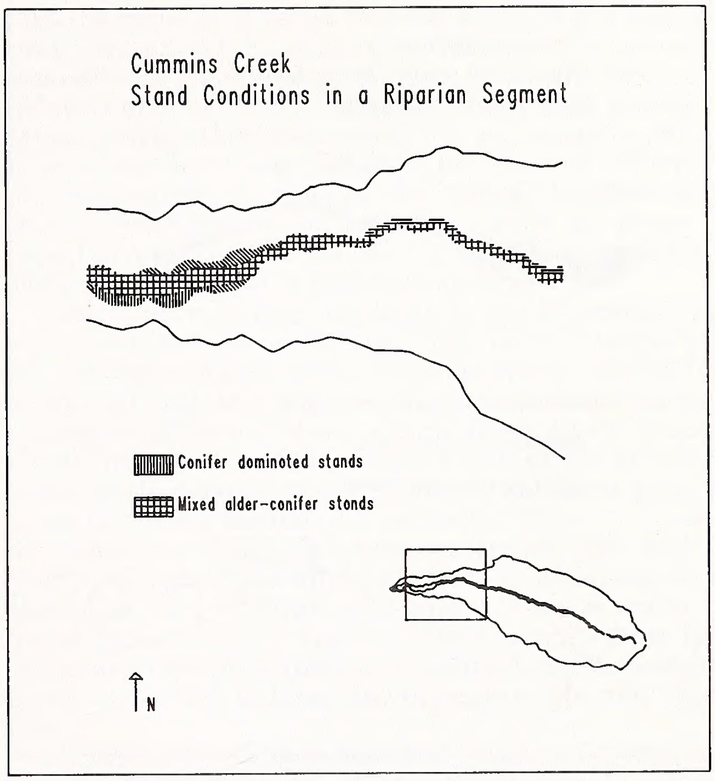
Riparian buffers can be generated by examining the stream channel in its valley floor context. Wide buffers might be left where a stream flows unconstrained through alluvial deposits. In this circumstance, the interactions between the stream and terrestrial ecosystem are dynamic (bank cutting, input of woody debris, development of spawning beds, etc.) and important. A stream running through a bedrock notch, on the other hand, has little opportunity for bank cutting or other interaction with the adjacent terrestrial ecosystem. In this instance, narrower buffers, reflecting needs for shade, slope stability, legal constraints or other factors would be appropriate.

GIS software usually includes automatic generation of variable width buffers around linear features. Unconstrained stream reaches, those running through open alluvial deposits, were buffered out to the edge of the valley floor (Figure 4). These areas may be highly productive fish habitat and dynamic in terms of terrestrial-aquatic interactions and fish production (Reeves et al. 1987). Since significant constraints to the channel are minor in most of the watershed, the buffer map for Cummins Creek does not reflect the level of complexity that will occur in other watersheds. Minimum buffers along constrained reaches in other stream systems might reflect thermal protection, minimum legal standards, or other constraints.

Potential Woody Debris Input

Large, woody debris plays an important role in stream structure and function in the Pacific Northwest (Bisson et al. 1987). Woody debris is instrumental in developing plunge pools that dissipate stream energy, provide rearing habitat for fish, and store sediments. Large, slowly decaying conifer wood provides a stable energy base for many aquatic organisms and stable stream structures. Debris torrents and bank cutting are two major sources of woody debris in natural systems. In the past, large wood was often removed from streams, to facilitate water transport of logs (Sedell and Duval 1985) for fear that it might block fish passage. Moderate accumulations of large woody debris are often only transient barriers and, in fact, may harbor large populations of rearing fish. Restoration of appropriate levels of large woody debris to stream systems is proceeding on many ownerships.

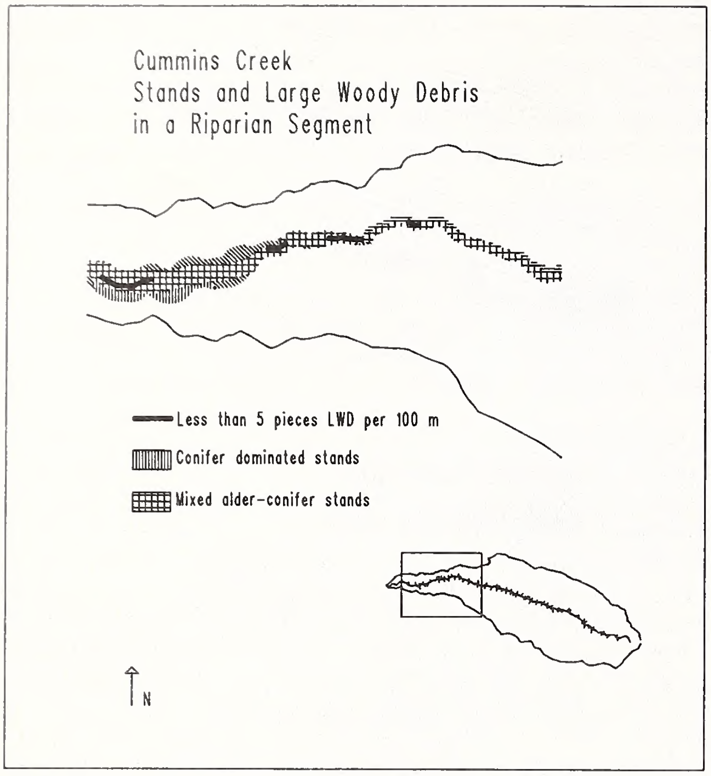
Figure 4.—Riparian buffers and stand conditions for a segment of Cummins Creek.


Cummins Creek
Stand Conditions in a Riparian Segment
Conifer dominated stands
Mixed alder-conifer stands
N

The morphology of the valley floor, which influences the degree of bank cutting and locations of inputs from tributary debris torrents, and current stand conditions, can be used to model potential natural recruitment of large woody debris. Current stand conditions indicate whether woody debris contributed through bank cutting of the riparian stand is likely to be small-sized, rapidly decaying hardwood or large, decay-resistant conifers. Stand conditions within the riparian buffer (Figure 5) were generated by overlaying a buffer based on valley floor width (Figure 4) with the watershed stand condition map (Figure 2). Because the buffer is, by definition, the active valley floor, its combination with stand conditions shows the kinds of large woody debris likely to enter the stream through bank cutting. An unconstrained channel running through a conifer stand will incorporate decay-resistant large wood during the course of channel movement. A similar channel running through a hardwood stand will incorporate rapidly-decaying, small-sized wood.

Potential natural recruitment can be combined with information about existing distribution of large woody debris to spotlight areas that are currently deficient in woody debris and where natural recruitment is unlikely to

Figure 5.—Areas currently deficient in large, woody debris along a segment of Cummins Creek.


Cummins Creek
Stands and Large Woody Debris
in a Riparian Segment
Less than 5 pieces LWD per 100 m
Conifer dominated stands
Mixed alder-conifer stands
N

provide sufficient amounts. The valley-floor reach-attribute data base contains information about amounts of large woody debris per 100 m of channel for each stream reach. An overlay of this information with the stand conditions in the buffer model indicates where the stream is currently deficient in large wood and also unlikely to accumulate significant amounts through bank cutting (Figure 5).

Discussion

The buffer model reflects the importance of terrestrial-aquatic interactions in the flood plain. The width of the buffer varies depending on the area within which the stream and adjacent terrestrial ecosystem can interact (Figure 4). Wide valley floors of alluvial material interact extensively with stream channels through input of woody debris, development of side channels, input of smaller organic matter, and shade. In addition, channels in wide alluvial valleys tend to develop pools, riffles, and glides suitable for fish spawning and rearing. Stream buffers based on valley floor characteristics reflect the importance of the valley floor in regulating the kinds of channel units and riparian processes likely to be present. Since the valley floor characteristics are stable over periods of centuries to thousands of years, they also indicate a relatively stable set of riparian conditions.

The Cummins Creek watershed is not characteristic of the Coast Range or Cascades in some ways. It lacks variation in valley floor morphology and channel constraint types that are common elsewhere. It is also a designated Wilderness Area and lacks an extensive history of timber harvest. As a result, stream enhancement projects may never be carried out in Cummins Creek. In fact, levels of large woody debris are good throughout the watershed. In watersheds where channel constraints such as bedrock gorges and landslides are more important, use of channel constraint type and valley floor width to generate buffers would produce more dramatic results. The total area in riparian buffers generated by this method compared to fixed-width buffers depends on the valley floor morphology and channel-constraint types present. An area of bedrock gorge might reasonably be buffered by the minimum allowed by forest practice regulations or by other considerations such as shade required to moderate stream temperatures. Buffers in a wide valley floor with unconstrained stream channels, where riparian productivity is likely to be highest, would be wider.

Stream Enhancement Application

A mixture of hardwoods and conifers forms the canopy along most of the valley floor (Figure 4). A few small conifer stands occur near the mouth of the watershed. Most of the woody debris falling into the stream from bank cutting will be small-sized hardwood stems. Since these decay fairly rapidly, the stream will likely be deficient in large, stable pieces, given no other source of input. Debris torrents from tributary watersheds have contributed substantial amounts of large wood at some tributary junctions. Low levels of large wood, less than five pieces per 100 m, exist in a some areas (Figure 5). Of these, a few occur in wide, potentially productive, alluvial flats. Those in the lower and middle sections of the watershed would be good places to plan placement of large pieces of wood through stream enhancement projects. The deficient areas in the upper watershed occur in an area constrained by inactive landslides and would not provide the kinds of channel conditions conducive to high productivity. Analyses of this kind allow prioritization of in-stream habitat enhancement projects.

Several areas within the productive, unconstrained flats of lower Cummins Creek lack significant amounts of large woody debris (Figure 5). The portions of these areas lying adjacent to conifer-dominated stands are likely to accumulate decay-resistant woody debris over the next few decades as bank-cutting occurs. Long-term sources of large woody debris are available, but short term amounts within the stream might not be optimal. In these areas, in-stream placement of woody debris would create better channel habitat until natural recruitment occurs.

Sections of the stream lacking significant large woody debris and running through hardwood-dominated stands (Figure 5) are not likely to accumulate decay-resistant woody debris from riparian stands. Since this portion of the drainage is also lacks tributaries likely to deposit large wood in debris torrents, long-term levels of large wood are likely to remain low. Silvicultural under-planting of the riparian hardwood- dominated stands with shade-tolerant conifers combined with in-stream placement of large wood or other structures would provide for the presence of sufficient amounts of large wood in both the short and long term.

In both these cases, some input of woody debris from stands on the valley wall could occur if the stream channel is near the edge of the valley floor. An additional data layer depicting topographic conditions, slope steepness in particular, could be used to model likely influences of hill-slope stands on the stream.

Other Implications

Other uses could be made of the information available in the GIS map layers. Both fish habitat monitoring and models of important watershed processes could be developed using map information and GIS modeling techniques.

Fish habitat evaluation and monitoring.—Fish habitat results from a complex interplay of geologic/geomorphic, climatic, hydrologic, and vegetative conditions in a watershed. Within a watershed, much of the condition of the stream channel derives from valley floor morphology, hydrology, disturbance, and terrestrial vegetation conditions. Given a particular stream size, valley floor morphology, geometry and condition of tributary basins, and riparian vegetation play a large part in moderately long-term (several hundred years) channel conditions (Swanson et al. 1987). These conditions determine the potential for large woody debris input and accumulation, the development of sediment-rich flats, and the kinds of structures and gradients that provide fish habitat. Analysis of the proportions of different kinds of fish habitat (e.g., pools, riffles, and glides), fish production (to the degree that it is not influenced by exogenous factors), and the condition of fish habitats over time can reasonably be stratified by stream size, valley floor morphology, and stand conditions.

Maps of valley floor morphology, tributary basin geometry and stand conditions, and information about channel conditions from fish habitat surveys could be combined with periodic surveys of fish populations to develop models of fish habitat and, to some degree, fish producing potential. Unfortunately, exogenous factors, such as commercial and sport fisheries, can make correlation of habitat quality and fish production difficult.

In addition, a sampling scheme to monitor the effects of management on fish habitat could be stratified by a combination of valley floor morphology, tributary basin geometry, stand condition, and stream size over several streams within an area of similar geology and climate. This approach would provide an efficient way to monitor changes in fish habitat and riparian conditions. Cummins Creek and other relatively pristine watersheds can serve as controls for intensively managed watersheds.

Debris torrent potential.—Shallow, rapidly moving debris torrents transport large amounts of sediment from hill slopes to stream channels in parts of the Coastal Northwest (Swanson et al. 1987). Debris torrents generally originate in steep concave head walls or from roads and landings. They deliver large amounts of sediments and organic debris to stream channels. Effects on the mainstem vary but include increased water turbidity, increased sediment loads in streams, scour of tributary and mainstem channels (often to bedrock), and impacts on streamside vegetation. Fish habitat can be improved, by the addition of stream structure, or degraded, by scour and loss of structure (Swanson et al. 1987). Road building and timber harvest often increase the incidence of debris flows several fold over that found in undisturbed drainages. The impacts of debris flow on a mainstem channel in the steep, dissected topography of the Oregon Coast Range are a function of the properties of the moving material and the geometry, roughness, and permeability of the surface over which it flows (Swanson et al. 1987).

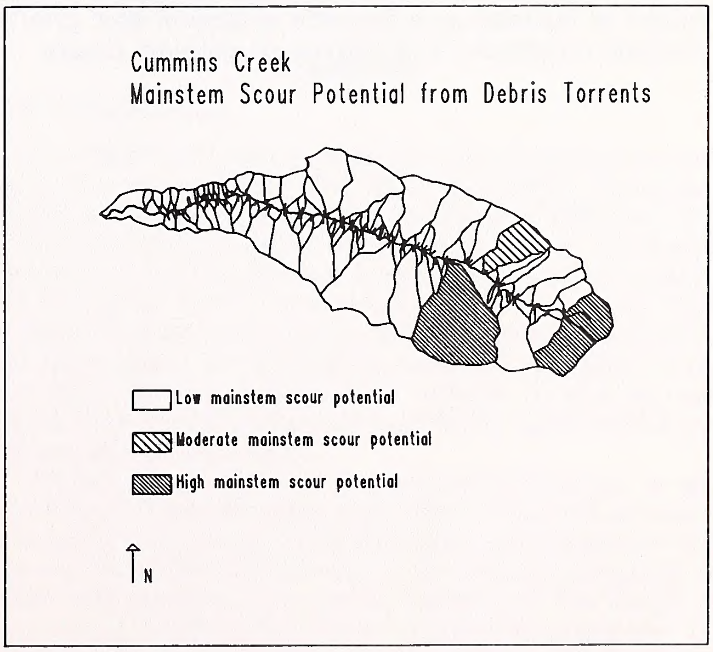
The factors which determine the distance a debris torrent will travel generally correspond to the geometry of tributary basins, the width of the mainstem floodplain, and the angle of entry of the tributary to the mainstem. A model based on these factors was developed for Knowles Creek (Swanson et al. 1987), a basin in an area of sandstone geology 32 km to the southeast of Cummins Creek. An initial application of this concept for Cummins Creek could use the angle of entry of the sub-basin tributary and the size of the sub-basin watershed to highlight sub-basins which are most likely to produce debris torrents that would scour the mainstem channel.

Swanson et al. (1987) suggest tailoring management to plan the impacts of debris torrents according to their runout potential and the current conditions of the mainstem. Some stream reaches lack sufficient large structural material for high-quality fish habitat. In these areas, occasional debris torrents that do not scour the mainstem would contribute beneficial large debris to the channel, increasing the fish-bearing capacity of the stream. In other areas, where abundant stream structures exist or where the potential for mainstem scour is high, debris torrents would likely be detrimental to fish-bearing capacity.

Nearly all tributary junctions in the Cummins Creek watershed show some evidence of debris torrent deposits in the last few hundred years. These generally take the form of alluvial fans and large woody debris accumulations at tributary junctions. Many debris flows likely occurred shortly after the major fires of the mid-nineteenth century. Most debris deposits in Cummins Creek show little evidence of having scoured the mainstem. This is a result of the relatively small tributary watershed size and the nearly perpendicular angle of entry of tributaries to the mainstem. A few large tributaries, however, enter the mainstem at shallow angles. Debris torrents from these could run down the mainstem for some distance, producing scour, loss of fish habitat, and impacts to riparian vegetation.

Cummins Creek is deficient in large woody debris in some locations (Figure 5). Debris torrents that do not scour the mainstem could provide beneficial stream structures in these areas. On the other hand, debris torrents from some sub-basins (Figure 6) could be very damaging because their watersheds are relatively large and could generate a large volume of debris material and enter the mainstem at a small angle, which could result in mainstem scour. Roading and timber harvest will not occur in Cummins Creek because it is Wilderness, but timber harvest and road build-

Figure 6.—Sub-basins of Cummins Creek with highest potential for mainstem scour following debris torrents.


Cummins Creek
Mainstem Scour Potential from Debris Torrents
☐ Low mainstem scour potential
▨ Moderate mainstem scour potential
▨ High mainstem scour potential
N

ing plans for nearby watersheds should consider the potential impacts of debris torrents on riparian conditions.

Watershed scale properties.—A GIS approach to watershed ecosystems encourages basin scale analyses of the kind required by land management plans and cumulative effects analyses. Many features of watersheds cannot be interpreted in the context of a single reach of stream. Water quality, wildlife habitat patterns, fish habitat, and sedimentation, to name a few, depend on processes that operate at a basin scale. Cumulative effects, by their nature, will often not be detectable over small areas and result from watershed or basin-level processes.

The cumulative effects of management impacts on riparian and channel features can be monitored and modeled using a combination of geomorphic province, tributary basin geometry, valley floor morphology, stand conditions, management activities, and increasing stream size within basins. Permanent sampling stations can be installed in combinations of fixed valley floor type and increasing stream size across a spectrum of management intensities to examine the accumulation of impacts downstream.

The relative value of fish and wildlife enhancement projects can be ranked at a basin level by examining them in a watershed context. Some projects, which seem valuable on a local scale, may be of lesser or greater value when seen on a landscape scale. Improving stream structural conditions for fish habitat in a local area might be of marginal value if cumulative impacts from upstream management will seriously impair water quality.

Network analysis.—The use of GIS maps and data bases describing important watershed biological and physical features should allow examination of watershed processes in an integrated fashion. For example, many advanced GIS packages include network analysis capabilities. A stream is a network that routes water and sediments. It should be possible to model basin wide patterns of water temperature, sediment movement and storage, peak flow timing and amount, and a variety of other features and processes using a GIS. For example, water temperature patterns in a basin might be modeled as a function of heating, topographic and vegetative shade, and inputs of cool water from tributaries. The routing and residence times of sediments of various sizes through a drainage might be modeled as a function of stream size, gradient, channel roughness, and sources of upstream inputs.

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Evaluation of the U. S. Forest Service "COWFISH" Model For Assessing Livestock Impacts on Fisheries in the Beaverhead National Forest, Montana

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Abstract.—The COWFISH fish habitat model developed by the U. S. Forest Service was evaluated during 1986 and 1987 at 43 stream sites within the Beaverhead National Forest, Montana to determine the ability of the model to assess effects of livestock grazing on trout fisheries. The COWFISH model uses a field survey of five variables (percentage of streambank with overhanging vegetation, percentage embeddedness, percentage of the streambank undercut, percentage of the streambank in an "altered" condition, and width:depth ratio) in association with channel gradient and the presence or absence of granitic parent material within the drainage to predict optimum and existing numbers of catchable (152 mm total length and longer) trout. The model predicted reasonable estimates of catchable cutthroat trout *Oncorhynchus clarki*, rainbow trout *O. mykiss*, and hybrids of these species ($r^2 = 0.65$; $P < 0.01$) at 19 sites where one or more of these forms occurred; however, predicted numbers of catchable brook trout *Salvelinus fontinalis* ($r^2 = 0.14$; $P > 0.05$) were imprecise at the 26 sites containing brook trout. Habitat suitability index results for field data collected by different observers did not appear to be significantly different ($P = 0.30$), and results for sites that deviated from model site criteria were not significantly different from sites that met site criteria ($P = 0.45$). Minor modifications in the model appeared to slightly improve model performance. Us of the COWFISH model by range professionals and livestock permittees did increase their awareness of the effects of livestock grazing on aquatic resources.

Several models have been developed for predicting fish standing crops in streams using various habitat parameters (Binns and Eiserman 1979; Binns 1982; Hickman and Raleigh 1982; Raleigh et al. 1984; Scarnecchia and Bergersen 1987). These models are generally data intensive and have limited applicability in a monitoring program, particularly for non-fisheries professionals. The COWFISH model was developed by Lloyd (1986) to address the needs of the Fish Habitat Relationships Program of the U. S. Forest Service (USFS). The model was developed primarily as a tool for range management professionals to document the effects livestock grazing has on aquatic resources on lands administered by the USFS. It uses a format similar to the Habitat Suitability Index Model Series developed by the U. S. Fish and Wildlife Service (e.g., Hickman and Raleigh 1982) and was developed using data and observations collected from Nevada, Utah, Montana, and Idaho.

A need was recognized by those who developed the model (J. Lloyd and B. Platts, USFS, personal communication) and USFS land managers for site specific data to calibrate and further validate this model. The objective of this study was to test the predictive capabilities of the model in comparison to existing numbers of catchable salmonids (152 mm total length and longer) by species on the Beaverhead National Forest, Montana, compare results obtained by different observers (including fisheries, range, and hydrology professionals and technicians), and explore modifications that may enhance the performance of the model.

Study Area Description

Forty-three study sites in 39 streams draining the Beaverhead National Forest were sampled. These streams were located in the Big Hole, Beaverhead, Madison, and Ruby river drainages in southwestern Montana. The streams ranged from first- to fifth-order tributaries, and channel gradients, average wetted widths, average water depths, and livestock grazing systems and intensities varied (Table 1).

Brook trout *Salvelinus fontinalis*, westslope cutthroat trout *Oncorhynchus clarki lewisi*, rainbow trout *O. mykiss*, and hybrids between rainbow trout and cutthroat trout were the predominant fish species present. Generally, cutthroat trout and rainbow trout were absent or present in extremely low densities in stream sections that supported brook trout. Exceptions were observed in sample sites in Jerry and Hunter creeks, where brook trout and cutthroat trout were present in similar densities.

The difficulty in identifying the difference between westslope cutthroat trout, rainbow trout, and their hybrids (using external morphological characteristics) forced combination of all these morphs into one category (*Oncorhynchus* spp.). Most stream sections that supported *Oncorhynchus* spp. contained westslope cutthroat populations that may have been introgressed to varying degrees with rainbow trout. Many stream sections also supported populations of sculpins *Cottus* spp.

Methods

COWFISH Surveys

The COWFISH habitat surveys were conducted according to the methods described by Lloyd (1986). These surveys were conducted during the summers of 1986 and 1987 by USFS range personnel from district offices, the Forest Hydrologist and hydrology technicians, and the author and biological technicians. Surveys were generally done for basic land inventory purposes, and therefore, a specialized randomized sample design was not attempted. However, the wide geographic area covered by the surveys should have minimized bias caused by the lack of randomized sample site selection.

District range personnel surveyed tributaries in the Beaverhead River drainage, hydrology personnel surveyed tributaries in the Ruby River drainage, but the author surveyed tributaries in all drainages. At all sites, a single 30- to 100-m long segment of stream was surveyed. The length of sections surveyed by the author varied by stream class: (1) streams with wetted widths less than 3 m, a 30-m section

Table 1.—Sample site characteristics for 43 sample sites where COWFISH habitat surveys and fish population estimate data were collected.

Stream	Reach	Stream order	Percent gradient	Average wetted width (m)	Average depth (cm)	Grazing system[a]	AUMs[b]
Bear Wallow	1	2	2.3	1.7	7.3	3P,RR	675
Bear Wallow	2	2	2.3	1.5	14.0	3P,RR	675
Beaver	1	3	3.3	0.9	20.1	8P,RR	11,610
Brown's Canyon	1	2	4.4	2.2	18.2	4P,RR	1,050
Bull	2	3	2.2	1.1	13.4	3P,DR	318
Burnt	1	2	6.8	1.8	20.7	8P,RR	11,610
Coal	1	2	1.7	4.9	22.9	8P,RR	11,610
Corral	2	2	4.6	1.5	22.9	8P,RR	11,610
Cottonwood	2	2	6.2	1.8	22.9	8P,RR	11,610
Cow Cabin	1	3	3.4	0.8	12.8	1P,DR	1,050
David	1	3	2.9	6.9	19.5	3P,RR	1,500
E Fk Ruby R	1	2	3.8	4.9	33.5	8P,RR	11,610
Effie	1	1	5.7	2.2	10.4	1P,SL	467
Elk Ck	1	3	1.7	2.8	17.4	5P.RR	1,584
Elk R	2	3	2.6	3.4	8.5	3P,RR	810
Gold	1	2	2.7	2.8	14.3	4P,RR	805
Governor	2	3	1.9	3.6	15.5	PVT	
Hunter	1	2	3.1	1.0	12.8	3P,RR	675
Jerry	2	3	3.5	4.6	15.8	5P,RR	2,745
Johnson (D-3)	1	4	0.7	6.2	20.1	2P,DR	495
Johnson (D-3)	2	3	4.4	5.5	11.9	2P,DR	495
Johnson (D-2)	1	4	4.8	4.0	13.1	5P,RR	2,745
Joseph	1	3	0.8	5.0	21.6	5P,RR	1,584
LaMarche	2	3	0.8	7.9	50.6	CLOSED	
Lost Horse	2	2	1.6	2.0	35.3	1P,SL	467
May	1	3	1.4	5.0	18.0	5P,RR	1,584
Meadow	2	3	7.8	2.7	13.1	2P,DR	304
Mono	2	2	1.3	1.4	34.1	3P,RR	1,500
Morrison	1	1	5.3	2.7	12.2	2P,RR[c]	633
N Fk Doolittle	1	3	6.3	2.3	15.2	4P,RR	1,465
Painter	1	2	4.7	3.4	15.2	4P,RR	1,050
Pass	1	2	5.5	3.2	4.9	2P,RR[c]	633
Ruby	3	4	0.8	4.5	22.6	1P.SL	2,094
Sheep (D-3)	1	3	1.7	3.3	21.0	5P,RR	1,584
Steel	1	5	0.5	7.9	17.7	PVT	
Steel	2	4	0.5	2.9	28.3	4P,RR	1,188
Teepee	1	3	3.4	2.2	10.0	7P,RR	8,565
Tie	1	4	0.6	5.1	25.2	2P,DR	189
Trail	2	4	0.8	3.7	25.3	5P,RR	1,584
W Fk Madison R	3	2	2.3	2.6	13.4	5P,RR	1,765
W Fk Ruby R	1	3	4.6	1.7	28.0	8P,RR	11,610
Wyman	1	4	3.8	4.7	18.6	4P,DR	2,134
Wyman	2	4	0.8	5.8	25.9	4P,DR	2,134

[a] Number of pastures, system code: SL= season long, RR= rest rotation, DR= deferred rotation, CLOSED= no recent use, PVT= private lands.

[b] AUM is animal unit months.

[c] These allotments had a history of season-long use with trespass.

was surveyed; (2) those between 3 and 6 m, a 150-m section was surveyed; and (3) those wider than 6 m, a 300-m section was surveyed. The range and hydrology surveyors always surveyed a 30-m long section.

Individual site applicability to site criteria described by Lloyd ("streams flowing through grass/forb riparian zones. . ." and streams that do not have "rocky streambanks") were ranked from 1 (indicating the criteria were met) to 3 (indicating the criteria were badly violated). Lloyd (1986) recommended that surveys be conducted at the end of the grazing period, but survey dates in this study did not always coincide with the removal of livestock from the pasture at the sample site. The only variable that may have been affected substantially by violating this criteria was the percentage of the streambank that contained overhanging vegetation.

Underlying parent material within the each drainage was classified as "granitic" or "non-granitic" using the "Ecological Land Unit" database developed by the Beaverhead National Forest. The database provides area estimates for geologic types in all of the study drainages (Beaverhead National Forest, unpublished data). Channel gradient at each site was estimated from U. S. Geological Survey (USGS) topographic maps (scale 1:24,000) by establishing a channel segment of at least 1.6 km which bracketed the sample site and determining the elevational difference within this segment.

In 1988, repeatability of the COWFISH survey was tested further at a single site in Antelope Creek, a tributary in the Madison River drainage. A total of six different two-person crews, ranging from those experienced with COWFISH field surveys to those with no survey experience, evaluated the same 30-m sample section. No attempt was made to train any of the surveyors. Each two-person crew completed their survey using the COWFISH instructions (Lloyd 1986).

Fish Populations

A 100- to 300-m long stream section was sampled at each site by the author and a biological technician to provide fish population estimates. Either a two-pass removal-depletion (Van Deventer and Platts 1985) or a mark-recapture estimator (Chapman 1951) was used to calculate abundance. Section length was determined as described above. Fish were captured by electrofishing in a downstream direction using a Coffelt BP-1C backpack shocker. An attempt was made to locate electrofishing sections with natural barriers located at the downstream end. Where no reasonable natural barrier existed, a block seine of 6.4 mm mesh was used at the lower end of the sample section.

Captured fish were measured to the nearest millimeter (total length) and held until after the second pass or marked using a fin-clip and released, depending upon the estimation technique. Separate estimates were made for fish from 75 to 151 mm and those longer than 151 mm (referred to as subcatchable and catchable, respectively, throughout the remainder of this paper). These size categories were selected to correspond with the definition of "catchable" provided by Lloyd (1986). Capture efficiencies for fish smaller than 75 mm were poor, and resulting estimates were not considered to be reliable. All estimates were expanded to the number of fish per 300 m of stream.

Fishing pressure at most sample sites was light. Many of the sites are relatively remote and support very few fish over 300 mm long, and anglers in this region generally prefer to angle for the trophy-sized trout available in all the major rivers. Since very few fish exceed 300 mm, it was felt that numbers of fish, rather than biomass, was a reasonable measure of fish standing crop.

Data Manipulation and Statistical Tests

Data from the field surveys, channel gradient, and the presence or absence of granitics within the drainage basin were used to calculate "parameter suitability indices (PSI)" for each variable, a final "habitat suitability index (HSI)", and predicted "optimum" and "existing" numbers of catchable salmonids per 300 m for each sample site (Lloyd 1986). The PSI values were calculated in a tabular fashion, and there was no attempt to interpolate between values. Statistical analyses were performed using the STATGRAPHICS program (STSC 1986), and Zar (1984) was used for statistical interpretation.

Distributions of final HSI values, actual estimated numbers of catchable *Oncorhynchus* spp. and brook trout expanded to number per 300 m of stream, and predicted "existing" numbers of catchable trout from the COWFISH model were tested for conformity to normal distributions using the Kolmogorov-Smirnov procedure. Differences in HSI values between observers and by site applicability to suggested COWFISH site criteria (Lloyd 1986) were tested for statistical significance by ANOVA. Estimates of HSI values, predicted number of "existing" catchable fish, and estimates for each of the variables in the COWFISH surveys were compared for the Antelope Creek site to evaluate differences between observers. These estimates were also compared to the estimates made by the author and the actual estimated number of catchable rainbow trout at the site.

Spearman rank correlations were computed between the estimated number of trout in the two length groups (catchable and subcatchable) and field data for the five COWFISH variables and the predicted number of catchable trout. To test the ability of the model to predict actual densities, the number of catchable trout estimated by electrofishing and the COWFISH predicted number of catchable trout by the two species groups were fit to a simple linear regression. These regressions were computed with and without forcing the intercept through the origin. Least squares methodology was used to develop curvilinear equations for converting field data to PSI values.

Results

COWFISH Surveys

Estimates for the five habitat variables assessed within the COWFISH model averaged 41, 46, 36, 50, and 20 for percentage of streambank undercut, percentage of streambank with overhanging vegetation, percentage of streambank altered by livestock, percentage cobble embeddedness, and width:depth ratio, respectively (Table 2). Final HSI values ranged between 15 and 85, and individual PSI values ranged between 0 and 1.0 (Table 2). The sampled population of HSI values was normally distributed ($P > 0.99$). Mean HSI values for the 19 sections that supported *Oncorhynchus* spp. and the 26 sections that supported brook trout (these counts include the Jerry and Hunter creek sample sites for both species) were 52 and 47, respectively.

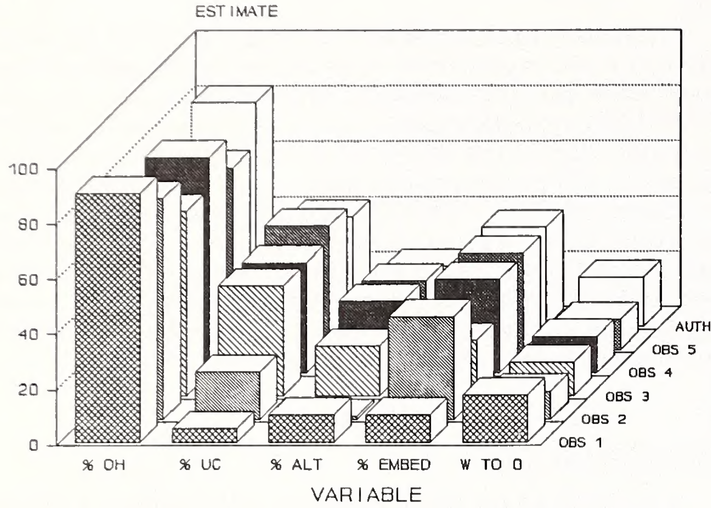
Mean HSI values stratified by observer were 46 ($N = 32$) for those sections surveyed by the author, 66 ($N = 6$) for those sections surveyed by district range personnel, and 54 ($N = 5$) for those sections surveyed by hydrology personnel. These differences were not significant ($P = 0.30$); however, this result may be confounded by site selection (sites surveyed by different groups of surveyors were often located in different river drainages) and small sample sizes for the range and hydrology surveyors. Mean HSI values for those sections that were ranked as best meeting the COWFISH site criteria, moderately meeting the criteria, and poorly meeting the criteria were 44 ($N = 10$), 52 ($N = 28$), and 51 ($N = 5$), respectively. Again, these differences were not significant ($P = 0.45$).

At the Antelope Creek site HSI values obtained from the six different survey crews averaged 60% of optimum and ranged between 54% and 62%. The author estimated the HSI value at 58% of optimum. Estimates for individual variables varied but were generally within an acceptable range (Figure 1). Estimates of the author were generally somewhat higher for individual variables; however, because of the compensatory way the variables enter the model (some enter as positive coefficients and others as negative coefficients) HSI values were similar.

Fish Populations

The estimates of the number of catchable and subcatchable *Oncorhunchus* spp. were normally distributed ($P > 0.99$ for both tests); estimates of catchable and subcatchable brook trout abundance were also normally distributed ($P > 0.41$ and $P > 0.22$, respectively). The distribution of

Figure 1.—Individual observer estimates for the five COWFISH variables. (OH - overhanging vegetation, UC - undercut banks, ALT - livestock bank alteration, EMBED - embeddedness, and W to D - width to depth ratio).



COWFISH model predictions of the number of catchable trout per 300 m did not deviate significantly from normal ($P > 0.21$) in *Oncorhunchus* spp. sites but did deviate from normal in the brook trout sites ($P < 0.05$).

Mean fish population estimates in sample sites containing *Oncorhynchus* spp. (number per 300 m of stream length) were 38 for subcatchable and 20 for catchable *Oncorhynchus* spp. (Table 3). Population estimates in sample sites that contained brook trout averaged 83 and 45 brook trout/300 m of stream for subcatchable and catchable length groups, respectively (Table 3). Mean population standard errors (expressed as a percentage of the estimate) were 7% and 3% for the above two size classes, respectively, in *Oncorhynchus* spp. sites and 11% and 6%, respectively, in the brook trout sites (Table 3). The Antelope Creek site contained an estimated 412 subcatchable (SE = 12.4) and 12 catchable (SE = 1.0) *Oncorhynchus* spp. per 300 m of stream length.

Correlations and Regression Analyses

Spearman rank correlation coefficients between estimated numbers of catchable *Oncorhynchus* spp. per 300 m and COWFISH variables were statistically significant ($P < 0.05$) only for the embeddedness variable (Table 4). For estimated numbers of catchable *Oncorhynchus* spp., correlations were significant between catchable *Oncorhynchus* spp. and COWFISH predicted optimum ($P < 0.05$) and existing ($P < 0.01$) numbers of catchable fish per 300 m (Table 4). No significant correlations were observed between estimated numbers of brook trout per 300 m and individual COWFISH variables or predicted catchable trout per 300 m (Table 4).

Regression between estimated numbers of catchable *Oncorhynchus* spp. per 300 m and predicted numbers of catchable fish per 300 m from the COWFISH model yielded a coefficient of determination (r^2) of 0.65 and was statistically significant ($P < 0.01$) (Table 5, Figure 2). Forcing the y-intercept through the origin reduced the coefficient of determination ($r^2 = 0.64$) and decreased the slope from 1.9 to 1.8 (Table 5).

Regression analysis for catchable brook trout yielded a low r^2 (0.14) and was not statistically significant ($P > 0.05$) (Table 5 and Figure 2). The fact that the distribution for the predicted numbers of catchable trout at the brook trout sites did deviate from normal ($P < 0.05$) may have affected the results for regressions at these sites. However, the lack of normality was probably related to the relatively poor condition of many of these sites with respect to COWFISH variables which resulted in many low predicted fish values. Removing sites that poorly fit COWFISH site criteria did not appreciably change the regression equation slopes or r^2 values for either the *Oncorhynchus* spp. and brook trout regressions (Table 5). Regressions between estimated numbers of subcatchable *Oncorhynchus* spp. and brook trout versus COWFISH predicted numbers of catchable trout were poor with r^2 values of 0.08 and 0.00, respectively.

At the Antelope Creek site, the COWFISH model estimates ranged from 10 to 16 catchable fish/300 m of stream and averaged 14 catchable fish/300 m (SE:0.9) for the six different survey crews. The actual estimated number of *Oncorhynchus* spp. was 12/300 m of stream length.

Model Modification

A third-order polynomial equation was used to relate field data to PSI values ($P < 0.01$) (Figure 3). The grouping of a wide range of field estimated values to a single PSI value for the embeddedness and width:depth ratios resulted in poorer fits for the respective equations. These regression equations provided a means of interpolation between tabled values and calculations within the model; however, the r^2 values in the regressions between predicted numbers and estimated number of catchable *Oncorhynchus* spp. and brook trout did not improve appreciably.

Discussion

COWFISH Surveys

The COWFISH survey techniques provided those in the range profession with a relatively simple, yet efficient, tool for evaluating the impacts of livestock grazing on aquatic resources. Differences in HSI values between observers or between sites that deviated from suggested site criteria were not statistically significant. These results indicate a high degree of robustness for the COWFISH model. It may be used even by surveyors with differing levels of experience and at stream sites with greatly varying habitat types such as willow *Salix* spp. and sedge *Carex* spp. communities. Fisheries and range professionals are presently refining the model for better application in willow communities, where rocky streambanks dominate, by replacing the undercut streambank component with another habitat variable. The most important feature of the methodology is that range professionals consider and observe livestock use as it affects streambanks and riparian communities.

Predictive Capabilities

The ability of the COWFISH model to predict densities of catchable *Oncorhynchus* spp. was promising, given the relative ease of data collection for the five habitat variables. The fact that the regression between estimated numbers of catchable *Oncorhynchus* spp. and the number predicted by the model was statistically significant indicated that the slope (1.9) can be used as a correction factor to improve the predictive capability of the model for streams in southwestern Montana.

The ability of the model to predict densities of catchable brook trout was disappointing. Modde et al. (1986) found

Table 2.—Estimates for habitat data required for COWFISH model and model generated "parameter suitability indexes (PSI's)" and final "habitat suitability indexes (HSI's)" by sample site.

		Estimated values (model PSIs) for five COWFISH variables					
Stream	Reach	Stream-bank undercut (%)	Streambank overhanging vegetation (%)	Stream-bank altered (%)	Cobble embedded-ness (%)	Width-to-depth ratio	Final HSI
Bear Wallow	1	11 (0.1)	38 (0.5)	59 (0.4)	45 (0.3)	23 (0.4)	25
Bear Wallow	2	53 (0.7)	60 (0.8)	24 (0.9)	56 (0)	11 (0.9)	65
Beaver	1	77 (0.9)	77 (0.9)	27 (0.9)	40 (0.4)	5 (1.0)	80
Brown's Canyon	1	48 (0.6)	100 (1.0)	11 (1.0)	5 (0.9)	12 (0.9)	85
Bull	2	78 (0.9)	92 (0.9)	39 (0.7)	73 (0)	8 (0.9)	65
Burnt	1	15 (0.1)	25 (0.4)	75 (0.3)	30 (0.6)	9 (0.9)	45
Coal	1	30 (0.3)	30 (0.4)	50 (0.4)	40 (0.4)	21 (0.5)	40
Corral	2	60 (0.8)	65 (0.8)	30 (0.8)	40 (0.4)	5 (0.9)	70
Cottonwood	2	80 (0.9)	100 (1.0)	0 (1.0)	50 (0.1)	8 (0.9)	75
Cow Cabin	1	20 (0.1)	85 (0.9)	40 (0.6)	2 (1.0)	6 (1.0)	70
David	1	47 (0.6)	6 (0.1)	46 (0.5)	57 (0)	36 (0.1)	25
E Fk Ruby R	1	7 (0)	20 (0.3)	66 (0.3)	25 (0.7)	15 (0.8)	40
Effie	1	46 (0.6)	28 (0.4)	41 (0.6)	54 (0.1)	21 (0.6)	45
Elk Ck	1	47 (0.6)	9 (0.1)	43 (0.6)	64 (0)	16 (0.8)	40
Elk R	2	5 (0)	47 (0.7)	61 (0.4)	58 (0)	40 (0.1)	20
Gold	1	27 (0.2)	28 (0.4)	33 (0.8)	46 (0.2)	20 (0.7)	45
Governor	2	43 (0.5)	52 (0.7)	13 (1.0)	27 (0.7)	23 (0.4)	65
Hunter	1	38 (0.4)	58 (0.8)	56 (0.4)	65 (0)	8 (0.9)	45
Jerry	2	26 (0.2)	38 (0.5)	45 (0.5)	39 (0.5)	29 (0.1)	35
Johnson (D-3)	1	36 (0.4)	69 (0.8)	18 (0.9)	61 (0)	31 (0.1)	40
Johnson (D-3)	2	44 (0.5)	92 (0.9)	10 (1.0)	56 (0)	46 (0.1)	50
Johnson (D-2)	1	23 (0.1)	37 (0.5)	38 (0.7)	62 (0)	30 (0.1)	25
Joseph	1	45 (0.6)	58 (0.8)	19 (0.9)	67 (0)	23 (0.4)	50
LaMarche	2	55 (0.7)	55 (0.8)	12 (1.0)	62 (0)	16 (0.8)	65
Lost Horse	2	69 (0.8)	70 (0.8)	52 (0.4)	95 (0)	6 (1.0)	60
May	1	66 (0.8)	71 (0.8)	22 (0.9)	71 (0)	28 (0.1)	70
Meadow	2	53 (0.7)	41 (0.6)	4 (1.0)	36 (0.5)	21 (0.6)	65
Mono	2	51 (0.7)	5 (0.1)	37 (0.7)	98 (0)	4 (1.0)	50
Morrison	1	32 (0.3)	14 (0.2)	49 (0.5)	15 (0.8)	22 (0.5)	45
N Fk Doolittle	1	59 (0.7)	54 (0.7)	29 (0.9)	68 (0)	15 (0.8)	60
Painter	1	12 (0.1)	100 (1.0)	6 (1.0)	5 (0.9)	23 (0.5)	70
Pass	1	52 (0.7)	21 (0.3)	43 (0.6)	10 (0.9)	67 (0.1)	50
Ruby	3	11 (0.1)	20 (0.3)	45 (0.5)	54 (0.1)	20 (0.7)	25
Sheep (D-3)	1	58 (0.7)	38 (0.5)	15 (0.9)	73 (0)	11 (0.9)	55
Steel	1	22 (0.1)	10 (0.2)	50 (0.4)	69 (0)	45 (0.1)	15
Steel	2	69 (0.8)	24 (0.3)	31 (0.8)	80 (0)	10 (0.9)	55
Teepee	1	45 (0.6)	49 (0.7)	73 (0.3)	80 (0)	10 (0.5)	40
Tie	1	50 (0.7)	45 (0.7)	50 (0.4)	69 (0)	20 (0.6)	45
Trail	2	29 (0.2)	13 (0.2)	20 (0.9)	15 (0.8)	14 (0.8)	55
W Fk Madison R	3	11 (0.1)	24 (0.3)	62 (0.4)	72 (0)	19 (0.7)	25
W Fk Ruby R	1	45 (0.6)	45 (0.7)	35 (0.7)	15 (0.8)	6 (0.9)	75
Wyman	1	27 (0.2)	46 (0.7)	28 (0.9)	48 (0.2)	25 (0.3)	45
Wyman	2	33 (0.3)	21 (0.3)	44 (0.6)	65 (0)	22 (0.5)	25

Table 3.—COWFISH model predicted number of catchable (fish 152 mm and longer) per 300 m of stream length and estimated number of *Oncorhynchus* spp. per 300 m of stream length and associated standard errors (expressed as the percentage of the estimate) for fish 75 to 151 mm and 152 mm and longer.

Species Stream	Reach	COWFISH predicted (number per 300 m)	Estimated number of fish per 300 m (SE as percent of estimate)	
			75 to 151 mm	152mm and longer
Brook trout				
Bear Wallow	1	4	63 (6)	53 (0)
Bear Wallow	2	14	63 (6)	40 (3)
Bull	2	10	37 (0)	23 (51)
Cow Cabin	1	9	17 (10)	20 (8)
Elk	1	4	84 (3)	26 (0)
Gold	1	15	10 (24)	10 (0)
Governor	2	19	55 (8)	156 (1)
Hunter	1	7	87 (2)	13 (15)
Jerry	2	4	38 (4)	8 (0)
Johnson (D—3)	1	6	68 (3)	52 (3)
Johnson (D—3)	2	7	130 (7)	26 (4)
Johnson (D—2)	1	2	10 (0)	16 (0)
Joseph	1	6	77 (8)	66 (2)
LaMarche	2	68	121 (66)	112 (17)
May	1	6	182 (2)	62 (1)
Morrison	1	10	3 (0)	10 (0)
N Fk Doolittle	1	3	12 (38)	6 (17)
Pass	1	13	110 (2)	47 (0)
Ruby	3	4	12 (38)	6 (17)
Sheep	1	6	27 (4)	22 (3)
Steel	1	3	316 (20)	73 (3)
Steel	2	7	38 (18)	14 (23)
Tie	1	7	16 (0)	50 (3)
Trail	2	8	193 (8)	83 (2)
Wyman	1	5	37 (8)	27 (4)
Wyman	2	4	245 (28)	157 (4)
Means			84 (12)	46 (9)
***Oncorhynchus* spp.**				
Beaver	1	12	—	13 (15)
Brown's Canyon	1	28	137 (4)	77 (3)
Burnt	1	12	53 (0)	27 (0)
Coal	1	16	44 (3)	36 (1)
Corral	2	16	43 (0)	27 (5)
Cottonwood	2	20	10 (0)	18 (0)
David	1	4	42 (29)	—
E Fk Ruby R	1	26	2 (0)	32 (4)
Effie	1	3	83 (2)	—
Elk R	2	6	—	6 (0)
Hunter	1	7	10 (0)	—
Jerry	2	4	42 (16)	16 (0)
Lost Horse	2	6	38 (12)	26 (2)
Meadow	2	3	18 (18)	2 (0)
Mono	2	4	22 (1)	9 (0)
Painter	1	20	87 (2)	47 (2)
Teepee	1	7	53 (8)	13 (0)
W Fk Madison R	3	7	14 (6)	14 (6)
W Fk Ruby R	1	19	22 (3)	20 (3)
Means			38 (6)	21 (3)

Table 4.—Spearman rank correlation coefficients (probability values) between estimated numbers of *Oncorhynchus* spp. or eastern brook trout per 300 m of stream and field data collected for the COWFISH model and the model predictions of optimum and existing numbers of catchable fish per 300 m of stream.

	Estimated number of *Oncorhynchus* spp. per 300 m		Estimated number of brook trout per 300 m	
COWFISH variables and predictions	75 to 151 mm	152 mm and longer	75 to 151 mm	152 mm and longer
Percentage of streambank undercut	- 0.01 (0.95)	- 0.14 (0.56)	0.23 (0.25)	0.08 (0.68)
Percentage of streambank with overhanging vegetation	0.08 (0.73)	0.33 (0.16)	0.03 (0.86)	0.04 (0.84)
Percentage alteration	- 0.07 (0.77)	- 0.09 (0.70)	- 0.19 (0.34)	- 0.29 (0.15)
Percentage cobble embeddedness	- 0.31 (0.18)	- 0.60 (0.01)	0.19 (0.35)	0.03 (0.88)
Width:depth ratio	0.22 (0.36)	- 0.17 (0.47)	0.21 (0.29)	0.27 (0.17)
Predicted number of potential catchable fish per 300 m	0.03 (0.88)	0.67 (0.005)	- 0.07 (0.71)	0.24 (0.23)
Predicted number of existing catchable fish per 300 m	0.08 (0.74)	0.80 (0.0007)	- 0.14 (0.47)	0.16 (0.41)

Table 5. Regression equations between COWFISH predicted numbers of catchable trout and estimated numbers of subcatchable and catchable *Oncorhynchus* spp. and brook trout.

Species group Length group	Modifications to equation	Equation	r^2
***Oncorhynchus* spp.**			
Catchable	Original equation	y= 1.90x - 1.91	0.65
	With zero-intercept	y= 1.79x	0.64
	Excluding sites with poor applicability to COWFISH	y= 1.97x - 3.28	0.64
	Using only sites with excellent applicability	y= 1.84x - 0.77	0.61
Subcatchable	Original equation	y= 1.23x + 23.59	0.08
Brook trout			
Catchable	Original equation	y= 1.28x + 32.87	0.14
	With zero-intercept	y= 0.17x	0.08
	Excluding sites with poor applicability to COWFISH	y= 1.13x + 38.62	0.12
	Using only sites with excellent applicability	y= 1.26x + 33.23	0.14
Subcatchable	Original equation	y= 0.06x + 82.71	0.00

Figure 2.—Simple linear regressions between COWFISH predicted numbers of catchable trout per 300 m and estimated numbers of subcatchable and catchable *Oncorhynchus* spp. and brook trout.

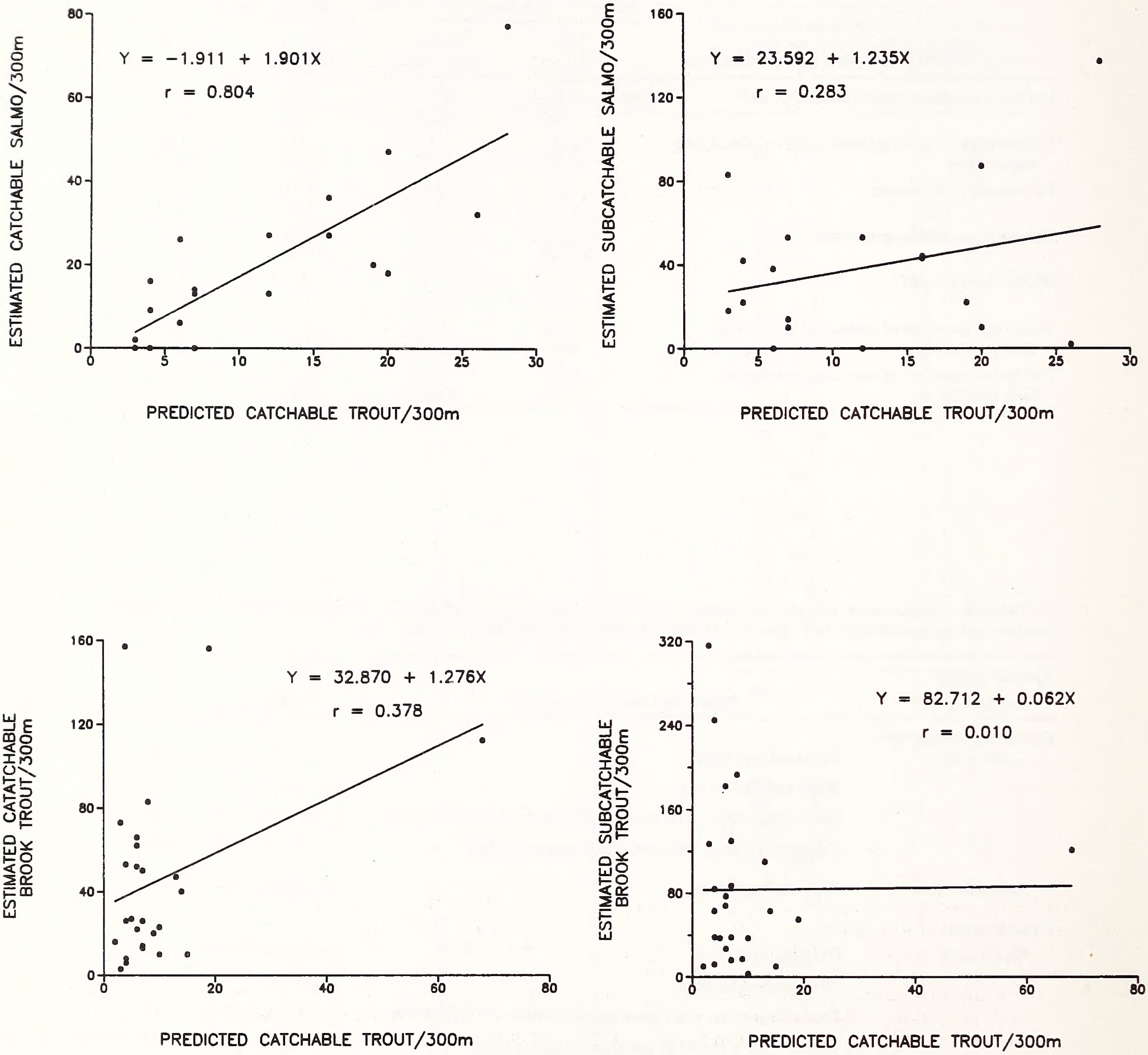
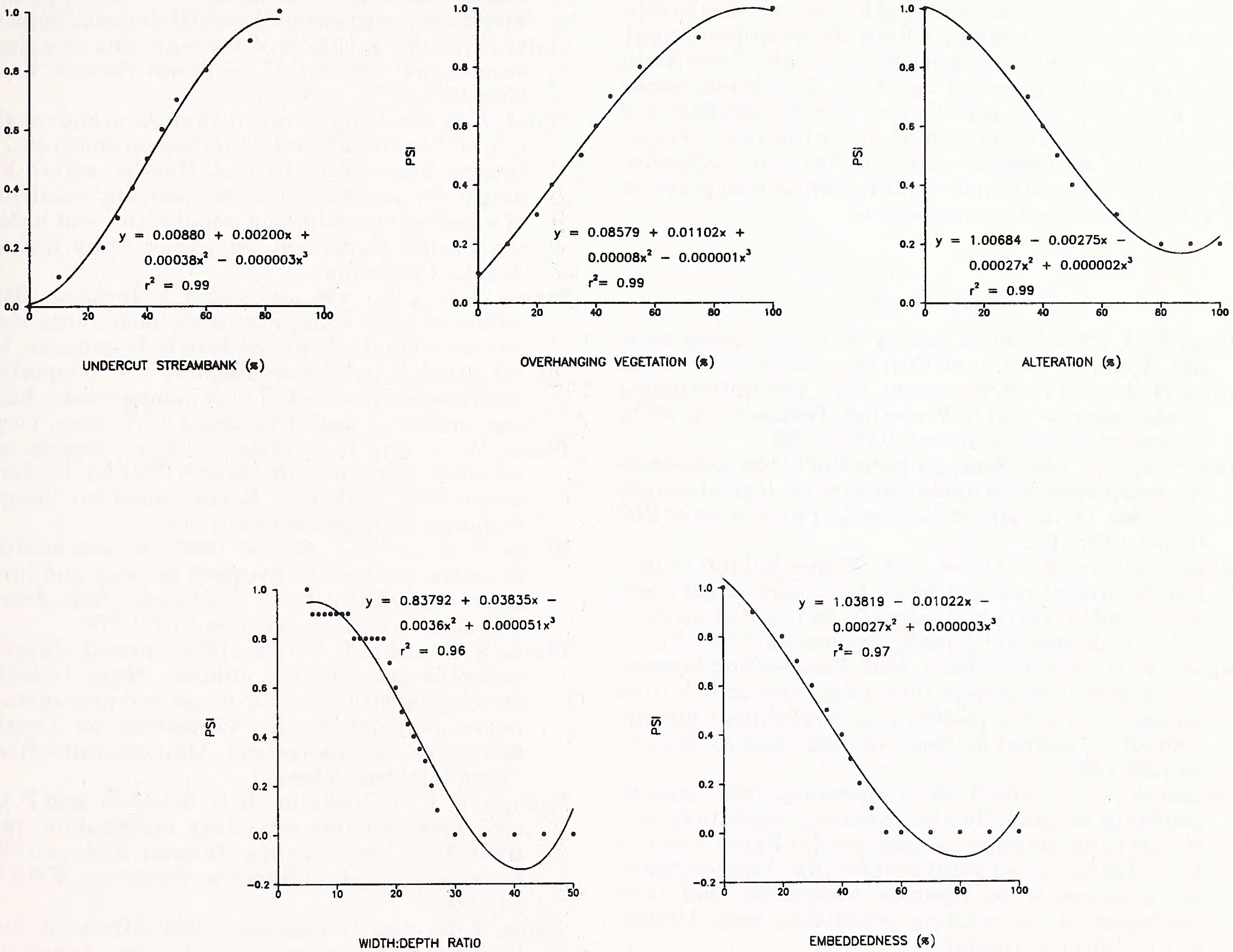


Figure 3.—Curvilinear relationships between actual measured values of percentage of the streambank undercut, percentage of the streambank with overhanging vegetation, percentage of the streambank in an "altered" condition, percentage cobble embeddedness, and width:depth ratio versus parameter suitability indices (PSIs).



that brook trout density was a poor indicator of moderate change in water quality associated with livestock grazing along a small stream in the Black Hills, but changes in density could be used as indicators of physical perturbations within the stream channel. Variables that have been related to brook trout abundance include instream cover, the presence or absence of beaver activity, and the presence of groundwater recharge to the stream channel (Stewart 1970; Fausch and White 1981; Cunjak and Power 1986). These variables have not been included in the model at present.

Predictive equations to convert field data to PSI values improved the performance of the model slightly. This improvement is related to the use of the equations to interpolate between tabled values. It may be possible to further refine the model for use in streams supporting brook trout by substituting different habitat variables assessed; however, the relationships between livestock use and the five variables now being surveyed have been well documented (Platts 1979, 1981a, 1981b; Platts and Raleigh 1982; Hubert et al. 1985; Marlow and Pogacnik 1985; Platts and Nelson 1985a, 1985b; Platts et al. 1985; Stuber 1985; Weltz and Wood 1986). Additional variables affected by livestock grazing that have been shown to influence trout abundance include invertebrate abundance (Rinne and Tharlson 1986), water temperatures (Theurer et al. 1985), and groundwater volume (Groeneveld and Griepentrog 1985). These additional variables would be extremely difficult for range personnel to assess in a simple survey.

The COWFISH model should not be used as a substitute for assessing changes in fish populations by quantitatively sampling those populations. Rather, the COWFISH model, and the survey data needed to use the model, allows for assessing trends in stream habitat condition and emphasizes the importance of maintaining high quality stream habitat to maintain fish resources. It can be used by range management personnel and grazing permittees to illustrate potential impacts of livestock grazing on stream fisheries.

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Mitigation Measures Recommended in Connecticut to Protect Stream and Riparian Resources from Suburban Development

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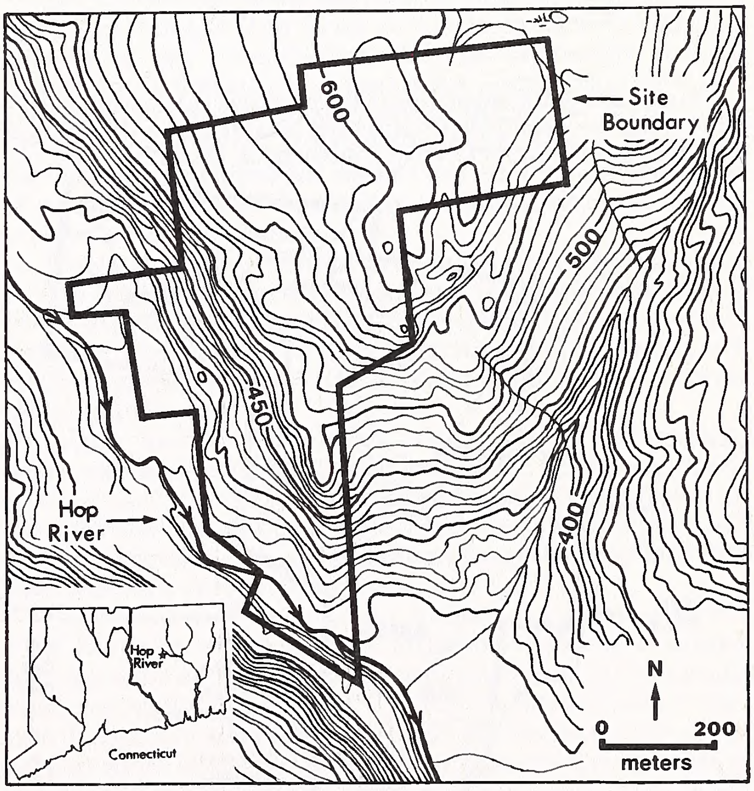
Abstract.—Accelerating suburban development in eastern Connecticut threatens to degrade valuable stream and riparian zone habitat. A representative case was the proposed construction of a large condominium complex along the Hop River, an important trout stream. An environmental assessment was requested by local officials to delineate impacts of residential development on the Hop River and recommend feasible mitigation measures. The following impacts were anticipated: (1) elimination of mixed hardwood-shrub riparian habitat, (2) soil erosion and sedimentation, and (3) percolation of heated, fertile septic effluent into the River. Cumulatively, these impacts will result in reduced trout and macroinvertebrate production as well as water quality degradation. Recommended mitigation measures were: (1) protect riparian zone habitat by maintaining a 30-m buffer along each side of the river; this buffer width is desirable due to site slopes greater than 15% and erodible soils, (2) install erosion and sedimentation controls during construction; controls include a filter fabric sediment fence, staked hay bales, and sediment detention basin, and (3) properly locate the community septic system to eliminate groundwater pollution. Stream protection requires conscientious planning by natural resource managers, developers, and local officials. Mitigation measures are mandatory to assist in the preservation of stream and riparian resources from the adverse effects of suburban development.

Economic prosperity and continued population growth in eastern Connecticut has led to explosive suburban residential development. Many proposed housing developments border or bisect invaluable stream and riparian habitat. A typical development was proposed to construct a 330 unit condominium complex on a 47-hectare parcel of land abutting the Hop River in Coventry, Connecticut. In addition to a put-and-take trout fishery, the Hop River was purported to support a native brook trout *Salvelinus fontinalis* population.

At the request of the town government, technical assistance was sought from the Connecticut Environmental Review Team concerning the impacts of the condominium development on the Hop River. Founded in 1969, the Environmental Review Team is an intergovernmental (regional, state, federal) and multidisciplinary team consisting of fisheries biologists, wildlife biologists, soil scientists, geologists, foresters, health department officials, and community land use planners (ERT 1988). Team members conduct a comprehensive environmental review of the proposed development site and file a report that will assist town officials and developers in reaching environmentally sound decisions concerning development proposals.

Specific features of the proposed condominium complex along the Hop River included a large on-site community septic system and water supply wells. Both would be located within the floodplain. Additionally, a horse stable, riding trails, tennis courts, and one road crossing were all planned to be constructed within the Hop River riparian zone. These features of the complex would alter or eliminate riparian resources of the Hop River. This paper is a synopsis of the aquatic environmental assessment conducted on the proposed development site, with particular reference to mitigation measures recommended to protect the Hop River and associated riparian zone resources.

Figure 1.—Location of the proposed condominium complex along the Hop River, Connecticut.



Study Area

The 47-hectare land parcel under consideration for development is situated on a western valley wall, atop an irregularly shaped hill, adjacent to the Hop River (Figure 1). Site slopes in many areas are steep, exceeding 15% (ERT 1987). Along the extreme southwestern edge, a natural floodplain has formed that is typically low-lying and flat. Except for the northernmost section of the site, all surface water flows downslope to the Hop River. Dominant soils (67% of the total area) on the site are Woodbridge, Montauk, and Charlton/Hollis (Figure 2; Table 1). The site also contains a variety of inland wetland soil types (Figure 2; Table 1).

The Hop River, approximately 23.9 km in total length, is a vital tributary of the Willimantic River (ERT 1987). At its point of outflow with the Willimantic River, the Hop River drains an area of 49.8 km^2 (ERT 1987). The river is prone to flooding throughout the reach that borders the proposed development site. Mean monthly discharge as recorded by a U. S. Geological Survey (USGS) gaging station (period of record 1933-1971) range from 10.4 m^3/s during August to 81.0 m^3/s during March (USGS 1971).

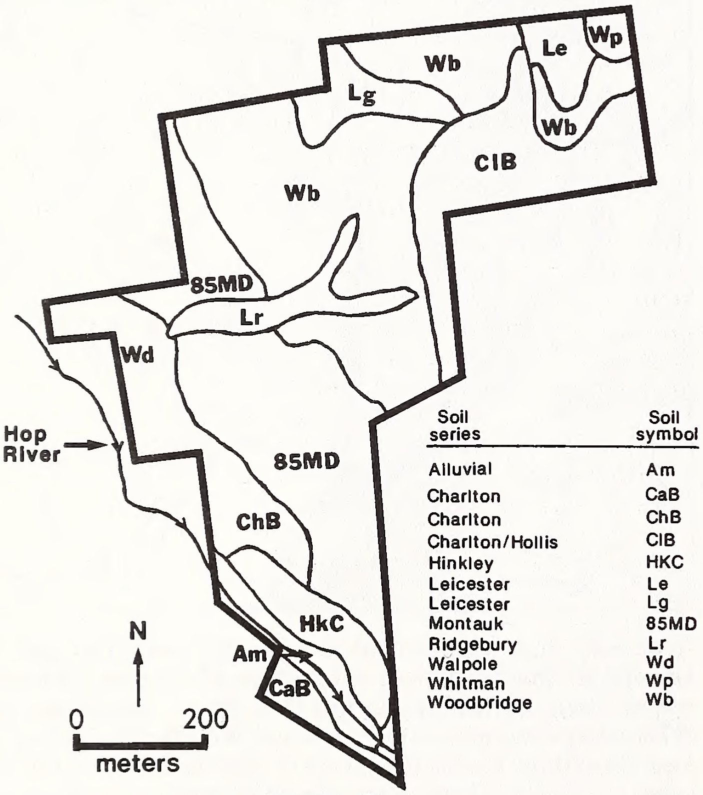
Table 1.—Proportional extent of soils on the proposed condominium site and their limitations for certain land uses (adapted from USDA (SCS) Soil Survey of Tolland County, Connecticut, December 1966).

Soil series	Soil symbol	Hectares	Urban use limitations[b]			
			On-site sewage	Buildings with basements	Streets and parking	Landscaping
Alluvial[a]	Am	1.7	3	3	3	3
Charlton	CaB	0.9	1	1	1	1
Charlton	ChB	1.9	1	1	1	1
Charlton/Hollis	CIB	5.9	variable	variable	variable	variable
Hinkley	HKC	2.2	3	2	2	3
Leicester[a]	Le	1.3	3	3	3	3
Leicester[a]	Lg	1.9	3	3	3	3
Montauk	85MD	10.7	3	3	3	3
Ridgebury[a]	Lr	2.0	3	3	3	3
Walpole[a]	Wd	3.0	3	3	3	3
Whitman[a]	Wp	0.8	3	3	3	3
Woodbridge	Wb	15.0	3	3	3	3

[a] Regulated inland wetland soils.

[b] 1 = slight (soil properties generally favorable for indicated use), 2 = moderate (soil properties can be favorable for indicated use if special design utilized), 3 = severe (soil properties not favorable for indicated use).

Figure 2.—Soil composition of the proposed condominium complex along the Hop River, Connecticut (adapted from USDA (SCS) Soil Survey of Tolland County, Connecticut, December 1966).



Methods

In eastern Connecticut, development proposals of concern are often reviewed by environmental review team members. Reviews are conducted in the following stepwise fashion:

(1) A preliminary meeting is held with team members, town representatives, town citizens, and the developer who presents detailed development plans and answers questions.

(2) After the meeting, team members move to the field to inspect the proposed development location and evaluate the distribution, quantity, and quality of natural resources. Members typically double-check mapped information such as soils, topography, and surficial and bedrock geology, and identify important vegetation, wildlife, fisheries, and riparian resources that may be impacted by development. If necessary, follow-up visits to the site are conducted.

(3) Reports are prepared by individual team members that delineate impacts and recommended mitigation measures to minimize impacts.

(4) The team coordinator compiles member inputs and sends them to town officials for public distribution.

Fisheries site evaluation during an environmental review is comprised of the following components:

(1) Evaluate local fishery and riparian resources that may be impacted by pre- and post-construction activities.

(2) Evaluate the potential for soil erosion and sedimentation events by determining site slopes and erodibility of local surface soils.

(3) Review septic system locations and determine capacity of subsurface soils to effectively dilute septic effluent.

(4) Review proposed water supply well locations and determine potential impacts to adjacent streams.

(5) Locate proposed road networks and stormwater discharge outlets.

(6) Identify areas where streams will be bridged.

Due to anticipated impacts to the Hop River and riparian resources, an electrofishing survey was conducted in the river adjacent to the proposed development site to ascertain fish species composition and relative abundance. Sampling gear consisted of a Coffelt BP-4 stream backpack electroshocker. All captured fish were identified and immediately released. Total lengths of all captured salmonids were measured to the nearest millimeter.

Results and Discussion

Stream and Riparian Zone Characteristics

The proposed condominium complex will border 1.3 km of the Hop River. Stream gradient along this stretch is 10.5 m/km. The portion of the Hop River adjacent to the proposed development varies from 3.0 to 7.6 m in width. It is characterized by large expansive pool and well-defined riffle habitats at approximately a 1:1 area ratio. Typically, a 1:1 pool-riffle ratio has been considered optimum for salmonid production and survival (Platts et al. 1983). Mean water depth is approximately 0.3 m. Water deepens in larger pools up to a maximum of 1.2 m. Dominant substrate as determined by the Wentworth classification index was fine sand, gravel, and cobble (Cummins 1962).

Two distinct riparian zones were observed. The riparian zone east of the Hop River was formerly used for agriculture. It contains a diverse mixture of upland hardwoods in the overstory such as sugar maple *Acer saccharum*, yellow birch *Betula alleghaniensis*, ironwood *Ostrya virginiana*, American sycamore *Platanus occidentalis*, and flowering dogwood *Cornus florida*. A dense understory shrub layer exists comprised of sweet pepperbush *Clethra alnifolia*, witch hazel *Hamamelis virginiana*, and multiflora rose *Rosa multiflora*. Ground cover contains a variety of wildflowers and small amounts of skunk cabbage *Symplocarpus foetidus*.

Conversely, more flood tolerant vegetation are found west of the Hop River within the floodplain. Dominant overstory hardwoods within this extensive wetland region are red maple *Acer rubrum*, common cottonwood *Populus deltoides*, black willow *Salix nigra*, and American elm *Ulmus americana*. A sparse understory under this dense canopy largely consists of speckled alder *Alnus rugosa*, and spicebush *Lindera benzoin*. Ground cover comprised a well-balanced mixture of skunk cabbage, false helleboor *Veratrum viride*, and a variety of ferns Polypodiaceae.

Resident Fish Population

The electrofishing survey revealed that the Hop River along the proposed development stretch supports a native brook trout population. Twenty-one native brook trout were collected within a 152-m sampling zone; total length ranged from 66 to 180 mm. In addition, four "wild" (naturally reproduced) juvenile brown trout *Salmo trutta* were sampled. Other species sampled in the Hop River were: blacknose dace *Rhinichthys atratulus*, longnose dace *Rhinichthys cataractae*, white sucker *Catostomus commersoni*, fallfish *Semotilus corporalis*, tesselated darter *Etheostoma olmstedi*, and common shiner *Notropis cornutus*. The diversity of indigenous fish species indicated that the Hop River provides excellent fish habitat. As expected, stocked trout were abundant in the area because the river is annually stocked by the Connecticut Department of Environmental Protection with more than 4,000 rainbow *Oncorhynchus mykiss*, brook, and brown trout.

Impacts

Impacts to the Hop River expected to occur if the design of the condominium complex remained unchanged and proper mitigative measures were not implemented included loss of riparian vegetation, soil erosion and sedimentation, septic system discharge, reduced stream flows, stormwater discharge, and disruption of fish movement.

Loss of Riparian Vegetation.—Construction activities would either permanently eliminate or alter the existing mixed hardwood-shrub riparian zone. The proposed river crossing, horse trails, community septic system, on-site wells, and tennis courts would all lie within the Hop River riparian zone. Research has shown that vegetated riparian zones serve to filter fine sediment, debris, and man-induced pollutants from penetrating streams (Karr and Schlosser 1977), assist in the regulation of stream hydrology (Bottom et al. 1985), and provide invaluable shading of stream waters that maintain ambient water temperature regimes necessary for salmonid survival (Raleigh et al. 1986). Any damage or alteration of the Hop River riparian zone would undoubtedly affect the ability of the zone to function properly.

Stream riparian zones that include wetland habitat can be afforded the most protection in Connecticut because strict regulations have been enacted regarding any proposed activity that may impact wetlands (CTDEP 1986). In the case of the Hop River condominium complex, only narrow bands of wetlands exist along the river adjacent to the proposed development; consequently, wetland regulations will offer minimal protection to the Hop River and the associated riparian resources.

Soil Erosion and Sedimentation.—Soil erosion and sedimentation of the Hop River would be expected from condominium site construction through increased surface runoff from disturbed unvegetated zones. Erodible soil types on this parcel present severe urban use limitations for residential housing developments (Table 1; Figure 2). Devegetation of riparian zones coupled with construction of condominiums on slopes greater than 15% could lead to serious erosion problems.

Excessive sediment deposition has reduced the survival of fish and macroinvertebrate eggs (Cordone and Kelley 1961), stream pool depth (Bottom et al. 1985), impaired gill function and normal feeding activities of fish (Oschwald 1972), and contributed to the depletion of dissolved oxygen (Ritchie 1972).

Septic System Discharge.—The proposed community septic system would be located within the Hop River floodplain. Leaching fields range from 15.2 to 83.8 m from the edge of river. An estimated 375 m^3 of sewage effluent would be discharged to the septic system from the proposed 330 two-bedroom unit complex on a daily basis.

Contamination and aquatic habitat degradation of the Hop River by septic system effluent would be expected because soils on the floodplain and within the building site were generally unsuitable for septic disposal (Table 1; Figure 2). Specifically, leaching field subsurface soils (silty sands) have lower permeabilities than overlying coarser sands and gravels; thus, effluent that enters this layer would tend to move laterally to the river, especially during the wet season, when the downward movement of excess water in the soil would be restricted.

Septic effluent could seriously impact the Hop River. Specifically, "heated" septic effluent could increase ambient stream water temperatures and bacterial decomposition rates resulting in decreased dissolved oxygen levels.

Reduced Stream Flows.—Reduced stream flows in the Hop River due to well operation would be expected. Since public water supply lines are currently not available at this site, the developer would need to rely on water bearing geologic formations from within the site for a water supply source. The proposed well field lies about 15.2 m from the

Hop River. Excluding fire protection and landscape irrigation, daily water consumption of condominium residents was projected to be 281 m^3. Because of their close proximity to the river, wells would likely be hydrologically connected to the river. During pumping periods, wells could lower the water table below the level of the river, drawing water from the river into the wells. This phenomenon, known as induced filtration, would be most critical during summer base flow periods. Diminished summer flows within the Hop River would cause a reduction of usable habitat for resident fish and aquatic macroinvertebrates.

Stormwater Discharge.—Stormwaters often contain salt, sand, nutrient-enriched sediment, gasoline, oil, and other harmful pollutants resulting in water quality and aquatic habitat degradation. Because of the high density of units proposed, development of the site would be expected to significantly increase the amount of surface runoff during periods of rainfall. These increases would result from soil compaction, vegetation removal, and the placement of impervious surfaces (rooftops, parking areas, and roads) over otherwise permeable soils.

Because of steep site slopes, the developer proposed the construction of a 30.5×53.3-m stormwater detention basin/pond to collect stormwaters before they could be discharged into the river. Although the engineered stormwater detention basin and catch basins along the proposed road network would trap most of the coarse, heavy particulate matter, they could not effectively remove fine particles, especially clays that remain in suspension.

Stormwater runoff exposed to "heated" road surfaces can marginally increase stream water temperatures. Other expected impacts to the Hop River were increases in water turbidity, specific water conductance, and stream sedimentation rates.

Disruption of Fish Movement.—The proposed precast box culvert for the Hop River crossing could disrupt diurnal and seasonal fish movements. Culvert installations have been found to block or impede fish movement primarily because of increased water velocities (Kay and Lewis 1970) or the production of shallow water conditions (Bryant 1981). If fish movements were permanently obstructed, groups of fish, particularly native brook trout, could become segregated, ultimately leading to fewer spawning interactions and lower population levels.

Recommendations

Riparian Buffer Zone.—The protection of stream and riparian resources at this site required maintaining at least a 30-m open space buffer zone along each side of the Hop River. Specific provisions of this recommendation were that no construction activities of any kind nor the elimination, alteration of riparian zone vegetation should take place in this zone. A 30-m buffer strip was warranted due to severe site slopes, erodible soils, and the presence of a native brook trout fishery adjacent to the proposed condominium complex. Although there is no predetermined distance or formula that can be used to calculate desirable and functional buffer strips on a site specific basis (Bottom et al. 1985), research has shown that 30-m wide buffers, 80% either vegetated or with stable rocky stream banks, normally provide adequate erosion control in moderate gradient areas of clearcut logging or overgrazed rangeland (OWIWC 1979). In some cases, severity of sedimentation events due to residential housing construction activities can parallel those observed after logging operations.

Recently, a 30-m buffer zone has become a standard recommendation by the environmental review team. However, final decision-making to implement buffer zones rests with town governments.

Erosion and Sedimentation Control.—A detailed erosion and sediment control plan should be designed for the construction site as specified by state and town regulations to reduce non-point sediment pollution from developed land and stormwater runoff from entering the Hop River. Specifically, the following recommendations have been suggested for this site.

(1) Land disturbance and clearing must be kept to a minimum. Condominium developments of the proposed size are usually implemented in three to five phases so that only areas that are actively being developed are exposed.

(2) Disturbed areas should be stabilized as soon as possible. Permanent structures, temporary or permanent vegetation, mulch, or a combination of these measures should be employed once land has been disturbed (CTCSWC 1988).

(3) The developer should install proper erosion and sediment control devices that effectively isolate the development site from surrounding areas. Staked hay bales or synthetic filter fabric fences should be installed downslope of areas under construction and also along the outer perimeter of the Hop River riparian zone.

(4) All sediment control devices should be monitored on a daily basis.

Septic System Placement.—The community septic system should be properly designed and located. All septic system leaching fields must be located in sufficient soils or fill depths so that effluents can be successfully eliminated.

The developer will be required to file for a special permit from the Connecticut Department of Environmental Protection because state statutes require permits for any development that will discharge in excess of 19 m^3/d of septic effluent. The developer must provide detailed technical information on the hydrogeologic conditions in the sewage effluent area.

Connecticut public health regulations require that septic system leaching fields be placed at least 15.2 m from any watercourse; however, recently approved town sanitary regulations require a minimum placement of 45.7 m from watercourses. Because proposed leaching fields range from 15.2 to 83.8 m from the river bank, the developer will have to relocate portions of the leaching fields further away from the Hop River.

Water Supply Placement.—Proper placement of community drinking supply wells in locations that could not alter Hop River stream flows should be required. It was strongly recommended that the developer be required to conduct a detailed hydrogeologic study in the area of the proposed wells that would address their impact on the river. Wells will have to be relocated to another area of the development if results show a definitive hydrologic relationship between Hop River discharge levels and well operation. Because proposed wells will pump in excess of 189 m^3/d or more, a water diversion permit will be required from the Connecticut Department of Environmental Protection.

Stormwater Runoff Control.—The developer must submit a detailed stormwater plan to calculate post development runoff. Catch basins on all roadways should be designed, located, and maintained to ensure the proper management of stormwaters and roadway runoff. Catch basins should be routinely maintained by the town to minimize impacts to the Hop River.

Because stormwaters should not be directly discharged to the Hop River, the developer proposed the construction of a detention basin/pond to collect post development runoff. The basin must be designed to regulate storm discharge from the site. Excessive stormwaters should be released after the Hop River flood discharges have peaked; otherwise, severe flooding and streambank erosion may occur downstream.

Stream Crossing Guidelines.—The proposed road crossing over the Hop River should be spanned by the construction of a bridge rather than the installation of box culverts. Although more costly, bridge construction will ensure unobstructed passage of all migratory and resident fish. Box culverts should be considered only if costs associated with the bridge construction are found to be prohibitive. It was recommended that box culverts be installed at least 30 cm below the existing streambed elevation. This installation criteria will provide for unobstructed fish passage and a natural accumulation of streambed material within the culvert.

Conclusion

Residential construction activities can inflict myriad impacts upon stream and riparian resources, but little attention has been paid to the development of comprehensive mitigation measures. In Connecticut, with the assistance of the interdisciplinary environmental review team, town governments are given technical information regarding impact assessment and the implementation of appropriate mitigation measures. Future protection of streams in Connecticut beyond existing wetland protections can be accomplished through the enactment of strict state laws governing land use within riparian zones.

Creating riparian buffer strips, controlling stormwaters, erosion and sediment, planning well and septic system placement, and crossing streams with care are vital mitigation measures which can lead to environmentally compatible development.

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Integrated Riparian Planning in the Urban Setting

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Abstract.—The City of Fort Collins, Colorado has implemented an innovative approach to riparian area creation and preservation. The solid foundation provided by farsighted plans (open space, basin master, urban fishery, wildlife, and national recreation area plans) are contributing elements to sensitive and sensible decisions concerning riparian areas. The citizens of Fort Collins, through these specific plans and actions, have been successfully protecting riparian areas. Thus lands and waters are being preserved that are beneficial to fish and wildlife and provide the citizens of Fort Collins with functional values such as flood protection and recreational benefits.

The city of Fort Collins, Colorado has implemented an innovative and integrated approach to riparian area creation and preservation. This approach has developed from citizen action and an open space plan that was prepared in 1974. Current initiatives include attempts to improve stream flows and the fishery in the Cache La Poudre River where it flows through Fort Collins and examining the feasibility of establishing a national recreation area on this portion of the river. Furthermore, non-structural measures have been emphasized in the planning and provision of the storm drainage function that has complemented an open space and riparian corridor plan.

Riparian Area Protection

In 1974, the Fort Collins City Council approved the Open Space Plan that is an element in the Comprehensive Plan of the City. The impetus for developing a program for open space preservation came from the Poudre Valley Greenbelt Association and the Environmental Task Force of Designing Tomorrow Today (City of Fort Collins 1974). These citizens encouraged the city officials and the community to take a greater interest in open space, parks, and trails. In April 1973, a 1% sales-tax increase was approved by the voters for capital improvements, including $2.4 million for open space land acquisition and $1.4 million for acquisition of additional parks. The Open Space Plan recommended acquisition of land along the Cache La Poudre River and Spring Creek, a tributary of the Poudre, for non-motorized recreational trail system, parkland, and open space. Because development pressure was strong along Spring Creek, the plan also recommended that dedication of the right-of-way for the trail should be required as development proceeds. Areas of unique vegetation and wildlife habitat were recommended to be acquired and be incorporated as part of the trail system. This was a farsighted recommendation because most valuable wildlife habitat, mature vegetation, and wetlands are found in floodplains (Flanagan 1988). The plan also noted that floodplains should be maintained as open space.

The Open Space Plan is being actively implemented with 24 km of trail constructed along the Poudre River and Spring Creek. The opening of a 11-km segment of the trail along the Poudre River in 1981 stimulated renewed interest in the River. People could easily experience the River and evaluate the conditions along this resource. Also, open space areas have been added to these corridors, preserving wetland and riparian areas, including three major community parks. This has occurred through acquisition and dedication. Sand and gravel companies operating in the Cache La Poudre floodplain through Fort Collins have dedicated open space to the City. After the sand and gravel have been removed, the companies have been donating the land to the City. This is an example of temporal multiple use of a natural resource.

Acquisitions have been funded from sales tax and Colorado Lottery proceeds. Sales tax funds provided most funding until 1985. Colorado Lottery proceeds since 1983 have been dedicated by the City Council solely for open space and trails. These funds have provided a steady source of revenue ($250,000 annually) to continue implementation of the Open Space Plan. This plan has proved to be a blueprint for implementation rather than simply a planning dream.

The most recent addition to riparian open space is the Gustav Swanson Nature area that is located along the River adjacent to downtown. The site is wooded with cottonwood *Populus* spp., willow *Salix* spp., Russian olive *Elaeagnus*, and ash trees *Angustifolia* with native grasses as the dominant ground cover (Fort Collins Audubon et al. 1988). The 4.25-hectare area is a cooperative effort of the City, Poudre River Trust, and the Fort Collins Audubon Society to create a handicapped-accessible interpretative habitat area that will ultimately include trails, a picnic site, observation areas, and wildlife demonstration areas. The trails have been laid, and the Native Plant Society and Audubon Society are identifying appropriate trees and other landscape additions.

Stormwater Function

Following recommendations in the Open Space Plan, the City Council adopted a storm drainage ordinance in 1976. This ordinance established a stormwater management program that is based on two principles:

(1.) Real property within a drainage basin will be benefitted by the installation of a storm drainage system.

(2.) The cost of installing a drainage system should be assessed against the real property in a basin.

The ordinance also created a Storm Drainage Board to advise the City Council on the development of a comprehensive drainage program. The Board is comprised of seven members appointed by the City Council, representing engineering, irrigation, economic, and legal interests. The Board is responsible for dividing the City into drainage basins (eleven at present), recommending basin master plans and the improvements for each basin, and a method of paying for these improvements.

In 1980, the City formed a stormwater utility by bringing together routine operations, maintenance and administration of the existing drainage system, and engineering and development of a comprehensive capital improvements program (Engemoen and Krempel 1983). A monthly fee was instituted by the City in 1981 to fund operations, maintenance, and administration. The fee is based on property size and land use. In 1983, the City Council approved an additional fee for capital improvements that varies according to the capital needs of each basin. The fee paid for each property is based on the extent that the property contributes to storm drainage. The average monthly fee in 1988 for a lot of approximately 600 m^2 was $3.44 for residential and $6.88 for commercial.

The 100-year storm was adopted as the storm drainage design criterion. Using this criterion, the basin master plans identify over $40 million in capital improvements. These improvements contain 'soft' or non-structural features including natural drainageways, creeks and rivers, man-made lakes, canals, and grass-lined open channels, and 'hard' or structural features such as storm sewers, culverts, and concrete-lined channels. Primary emphasis in Fort Collins is on non-structural features. Soft improvements are generally more economical than hard improvements as long as rights-of-way are not a constraint. In addition, water quality of storm runoff is generally improved by contact with natural surfaces at low flow velocities (Martin 1988). Also, temporary storage in detention ponds allows settling of suspended pollutants. Only 6% of the 1988 capital budget is being spent on 'hard' improvements.

Emphasis on non-structural improvements in Fort Collins has triggered coordination with other City departments thus providing opportunities to integrate the storm drainage function into other community considerations. For example, several regional detention areas have been located adjacent to and incorporated into public parks. A major drainageway, Spring Creek, has a foot and bicycle trail along its course through Fort Collins. Also, Development Services is working closely with the Stormwater Utility to encourage designing drainageways as open space for new developments. Preserving the floodplain protects wetlands, wildlife habitat, fish, vegetation, and scenic vistas, and the public is provided with linear parks for recreational activities (Flanagan 1988).

The effects of stormwater on the quality of receiving waters has been investigated in Fort Collins through chemical monitoring and a biological assessment. Problems identified in sustaining aquatic life in Spring Creek include:

(1.) Diminished stream flows during parts of the year caused by irrigation diversions during the spring and summer months;

(2.) Lack of adequate pool area for resting, cover from predators, and protection during winter months; and

(3.) High sediment load and subsequent smothering of substrate with associated reduction of macroinvertebrate population size and diversity.

A report is being prepared that will include a summary of habitat conditions biotic integrity, and habitat enhancement potential.

To reduce sediment loading of water bodies, the Stormwater Utility is also preparing grading/erosion guidelines. Other purposes of the guidelines are to control soil erosion and modification of significant vegetation communities by requiring proper provisions for water disposal and the protection of soil surfaces during and after grading activities. The Stormwater Utility is encouraging the voluntary use of construction site erosion control measures and is conducting an education program on erosion control.

Urban Fishery Plan and Water Rights

Recognizing the need to improve the fishery in the Cache La Poudre River, the City, Poudre River Trust, and Rocky Mountain Flycasters (a local chapter of Trout Unlimited) jointly developed the Poudre River Corridor Fishery Plan that was approved by the appropriate governing boards in 1987. The plan outlines the steps that will be necessary to evaluate the fishery potential of the Cache La Poudre River as it flows through town and includes an approach to selecting and implementing alternatives for improving the River. The project consists of five phases: preliminary modeling of fishery potential, fishery potential analysis, hydrological analysis, implementation, and evaluation. Phase I was completed in November 1987 (Nelson 1987), and a detailed work plan has been prepared (Tom Pitts and Associates 1988). Conditions are marginal for a fishery because flows are below 0.28 m^3/s for 8-9 months of the year. Physical and legal constrains make this plan a challenging project.

In December 1986, the City of Fort Collins filed an application for conditional water rights on the Cache La Poudre River for municipal purposes including fishery and recreation uses. This was done to protect unappropriated river flows. The Colorado Water Conservation Board and others filed objections to the application. The Board asserted that they are the only entity under Colorado law that can appropriate flows for any instream purposes. The City and other water groups in the area began working cooperatively to identify and evaluate exchange and management options to accomplish the instream requirements for recreation, revitalization, and fishery projects through Fort Collins. An agreement has been reached in which the City amended its filing to include a stream reach bounded by two diversion points for recreation, fishery, and wildlife purposes rather than claim an instream flow throughout the urban corridor. The Colorado Water Conservation Board has withdrawn its opposition because the modified application is consistent with the more traditional water filings in which water must be diverted, possessed, or otherwise controlled.

The lower diversion point will be a diversion structure for channel restoration of the Cache La Poudre River. The purpose of the structure is to divert low flows back into the river channel as it flowed through the Colorado State University (CSU) Nature Center prior to the high 1983 and 1984 runoff events. This structure resolves a number of problems: it takes advantage of the valuable fish habitat in the old channel so that habitat does not have to be created in the new channel in conjunction with the Poudre River Corridor Fishery Plan, it provides water for the mature stands of trees along the old channel in the Nature Center, and it protects the effort that CSU has extended to maintain the Center. Logs in the old channel and undercut banks, supported by living trees that occur every 30 m or so along the old channel, provide the habitat diversity needed to sustain a diverse community of fishes.

Natural Resources and the Wildlife Habitat Management Plan

The 1983 controversy surrounding the siting of an Anheuser-Busch brewery in Fort Collins was the catalyst for the creation of the Natural Resources Department of the City of Fort Collins in 1985. The City administration and the Council realized that the City staff lack the expertise to address a number of technical resources issues involving the siting of the brewery. As often happens, a crises situation fostered development of a farsighted policy. The Department consists of a small scientifically trained staff that helps to identify key natural resource issues and options. In Fort Collins, natural resources also encompasses a grass roots philosophy through a citizen natural resources board that guides policy development.

The Department is developing an extension of the open space and fishery plans through a wildlife habitat management plan that identifies sensitive wildlife and riparian habitats. The areas are classified for protection. Dedication of 'significant' areas and replacement of some wetland/upland environments at other locations will be considered as mitigation possibilities. The habitat plan has been distributed to other City departments, boards, and commissions for comments. The plan will be incorporated as part of the planning evaluation system of the City, the Land Development Guidance System.

The City organization is striving to make natural resources protection part of the organization's fabric. The goal is to examine the full range of available options and design policies, programs, and projects from the conceptual stage with an eye towards resources protection.

Towards that end, the City instituted an 'Environmental Awareness and Habitat Protection Program' in 1987. The program was, in part, initiated because of a number of land modification activities that were environmentally unsound. The objective of the program is to increase awareness among developers and program managers that certain activities have detrimental effects on natural resources, especially riparian areas, and that the purposes can be accomplished in more environmentally sound ways. The program began in January 1987 with an all-day symposium attended by 150 developers, contractors, landscape architects, and public project managers. The 1988 natural resources symposium was attended by over 250 citizens. Since March 1987, monthly environmental awareness sessions have been held addressing such topics as habitat protection for Fort Collins; Cache La Poudre River projects including the corridor fishery plan; Corps of Engineers 404 permit process; and a discussion of geese, ducks, and raptors in Fort Collins. The activities of the Natural Resources Department including the environmental awareness training have made project managers in the City more aware of environmental protection needs, and, more important, managers are incorporating effective protection measures into specific projects.

National Recreation Area

When the upper reaches of the Cache La Poudre River were designated as Wild and Scenic in October 1986, Congress also mandated that a feasibility study be done on the lower reaches of the river to see if it should be designated by the U. S. Congress as a Natural Recreation Area. Such areas have natural endowments well above ordinary quality and recreation appeal, but are of lesser significance than unique scenic and historic elements of the National Park System. National Recreation Areas afford quality of recreation experience that transcends levels normally associated with areas provided by State and local governments. These areas are intended to provide a high level of recreation use appropriate to the setting, through the conservation and enhancement of scenic, historic, natural, and other values that contribute to public use and enjoyment of the area. National Recreation Areas present opportunities for wildlife conservation and floodplain management. The Cache La Poudre River, as it flows through the Fort Collins area, is still relatively undeveloped and provides many opportunities for different kinds of recreation and natural resource conservation. The feasibility study, which is being jointly managed by the City of Fort Collins, Larimer County, and the U. S. Forest Service, is examining present and probable future conditions of the river and adjacent lands including physical, natural, and social opportunities and constraints. The final recommendation of the study will be reflective of community values and will be sent to the U. S. Forest Service by October 1989.

Conclusions

Funding is the key for the implementation of plans, and plans are the key to identifying opportunities. It is important to first have a plan; funding will follow. Riparian areas have been and will be successfully protected through the plans and actions of the citizens of Fort Collins. The need for an enlightened community, council,and staff committed to natural resources cannot be over emphasized. The solid foundation provided by farsighted plans (open space, basin master, urban fishery, wildlife, and national recreation area) are contributing elements to sensitive and sensible decisions concerning riparian areas. In Fort Collins, Colorado riparian areas provide community functional values that are being incorporated into the urban landscape.

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Interrelationship Between Watershed Condition and Health of Riparian Areas in Southwestern United States

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Abstract.—Sensitive hydrologic interrelationships exist between watershed condition and the health of associated riparian areas in the southwestern USA. The impact of extensive unmanaged livestock grazing, wildfires, and past forest clearing, coupled with numerous small linear perturbations such as travelways, low standard roads, and livestock trails, has dramatically illustrated the interrelationship between watershed condition and riparian health. Vegetation removal and soil compaction substantially increased surface runoff, produced sediment-laden flows, and increased erosive power to the channel system, upsetting the balance between riparian areas and the surrounding watershed. This led to the degradation, or in some cases complete destruction, of many riparian areas. A key factor in improving deteriorated riparian areas is understanding the balance that existed between watershed condition and riparian health in near pristine conditions. Under such conditions, watershed slopes and riparian channels were able to dissipate rainfall and concentrate flow energies produced during different precipitation events. This paper discusses the interdependency between hydrologic processes operating on upland slopes of a watershed and the channel processes affecting downstream riparian stability in the southwestern USA. A synthesis of this information is used to outline a method for assessing the capability of a watershed-riparian system to attain acceptable low-maintenance conditions in response to different rehabilitation treatments.

Riparian areas are closely interrelated with the surrounding watershed. For example, riparian communities stabilize stream channels (Riedl and Zachar 1984), provide repositories for sediment (Lowrance et al. 1986), serve as nutrient sinks for surrounding watersheds (Lowrance et al. 1984), and improve the quality of water leaving the watershed (Schlosser and Karr 1981). They also provide temperature control through shading, reduce flood peaks by providing resistance to flow, and serve as key recharge points for renewing ground water supplies (McGlothlin et al. 1988). However, riparian areas must be managed within the context of the entire watershed because all tributary effects cumulate to influence riparian health and stability. A delicate balance exists between riparian communities and the conditions of the watershed in which they reside. Upland watersheds in satisfactory condition absorb storm energies, provide regulation of stormflows through the soil mantle, and, as a result, provide stability to the entire watershed. This, in turn, provides sustained flows necessary for supporting healthy riparian ecosystems.

In contrast, watersheds receiving past abuse have developed channel systems throughout the watershed, including ephemeral gully networks, in response to increased surface flows which cause headcutting and gully formation. These gully networks cause rapid, concentrated, surface runoff which increases peak flows and produces large amounts of sediment. Past abuse and overuse of wildlands throughout the southwestern USA by grazing, trail and road construction, timber and fuelwood harvesting, mining, and other land uses have not only destroyed plant cover and increased soil erosion but also, in the process, reduced valuable riparian habitat.

A large body of information is available on watershed abuse and its effect on the condition of a watershed. Likewise, a considerable amount of information is emerging which describes the factors necessary for maintaining healthy riparian areas (e.g., streamflow duration, channel stability and configuration, grazing management, etc.). However, we are not aware of any publication which stresses the interdependency between the health of riparian areas and upstream watershed condition when developing rehabilitation strategies. Therefore, in this paper we (1) discuss the interdependency between watershed condition and riparian health, (2) identify specific hydrologic processes important for maintaining an acceptable balance between riparian areas and the surrounding watersheds, and (3) provide guidelines for developing rehabilitation strategies based on the balance between watershed condition and riparian health. Although this paper focuses mainly on rangelands in the southwestern USA, some of the general principles developed have application on forests and brushlands throughout the western USA.

Riparian Health and Watershed Condition

"Riparian health" refers to the stage of vegetative, geomorphic, and hydrologic development, along with the degree of structural integrity exhibited by a riparian ecosystem. As such, riparian health reflects an equilibrium condition between aggradation and degradation processes operating within the riparian area, which is dependent upon the condition of the surrounding watershed. The term "watershed condition" describes the state of a watershed. It effectively integrates a number of resource factors including vegetation cover, flow regime, sediment and nutrient output, and site productivity (Hanes et al. 1986). In essence, the riparian communities reflect both biotic and abiotic conditions of the watershed in which they reside. A major assumption underlying the discussions in this paper is that a healthy riparian community reflects a dynamic balance between the riparian ecosystem, including the associated channels, and the hydrologic and geomorphic processes operating in tributary watersheds. Furthermore, it is implicit in this assumption that healthy riparian areas require stable watershed conditions to maintain and perpetuate themselves. However, the converse is not necessarily true; that is, watersheds in satisfactory condition require a healthy riparian area. Concentrated activities in the riparian areas (e.g., grazing and placer mining activities) may severely disturb the riparian areas but not affect the surrounding watershed.

The balance between watershed condition and riparian health represents a dynamic interrelationship between runoff and erosive forces where precipitation forces producing runoff are counteracted by vegetative, geomorphic, and structural resistance. When this natural system is in equilibrium, it maintains a level of stability tending to dissipate potential energies that would otherwise cause rapid changes. This resistance to change emanates from a combination of factors acting together throughout a watershed. Most important of these factors is vegetation. The relationship between vegetation cover and runoff and erosion has been extensively documented for wildland areas throughout the western USA by numerous investigators for several decades (Forsling 1931; Craddock and Pearse 1938; Woodward and Craddock 1945; Packer 1951, 1953; Dortignac and Love 1960; Rich and Reynolds 1963; Lusby 1970; Gifford 1976; Busby and Gifford 1981, Gifford 1985). Flows in excess of channel capacity overflow onto floodplains where vegetation and other debris provide a substantial resistance to flow and act as filters for sediment (Lowrance et al. 1984).

A watershed-riparian system in balance is also resilient. Most of the potential runoff produced by storms immediately infiltrates into the soil, and thus provides a more regulated flow according to the variable source area concept (Hewlett and Troendle 1975). Excess runoff reaching the channel increases flow volume and velocity, and this short-term increase in flow causes an oscillation in the balance between erosion and deposition. While the balance tips back and forth, it is quickly dampened by the channel characteristics. As a result, there is no permanent change in the central tendency toward maintaining an equilibrium between aggradation and degradation processes in the riparian area. The resilience, or elasticity, of the system is not violated, and little perceptible change in the apparent balance or erosional tendency occurs.

The balance between watershed condition and riparian health is well substantiated by recent reviews describing pristine riparian areas throughout the southwestern USA (Dobyns 1981; Minckley and Rinne 1985). These accounts portrayed these riparian areas as stable, aggrading stream networks containing substantial amounts of organic debris and supporting large beaver (*Castor canadensis*) populations. Under these conditions, headwater tributaries provided a continuous supply of small and large organic debris that formed log steps in smaller streams (Heede 1985), and large accumulations of logs and other organic debris along larger order, low-elevation mainstreams (Minckley and Rinne 1985). Naturally occurring floodplain and channel structures, along with living plants, dissipated energy, controlled sediment movement and deposition, and thereby provided a regulated sustained flow. These factors provided a hydrologically stable environment necessary for maintaining and perpetuating healthy riparian communities. The energy dissipation decreased flow velocities in stream channels and on floodplains, which improved percolation of water into subsurface storage. This delaying effect was likely enhanced because many stream channels were above fault-fracture zones that led to underground aquifers (McGlothlin et al. 1988). Water stored in these high-elevation aquifers was available and, when slowly released, supported late-season flows in downstream riparian areas. Sufficiently dense vegetation and ground cover were present throughout the watershed, which allowed most precipitation from storm events to infiltrate into the soil. Water passing slowly through the soil mantle sustained the dependable perennial streamflow necessary to maintain downslope riparian communities. It is important to note that under a pristine regime, where most storm events infiltrated into the soil, channel networks were less extensive (Carlston 1963). In particular, swales and slopes were generally free of incised channels and gullies. Flows also typically contained lower concentrations of sediment. Sustained flow provided a favorable environment for extensive riparian vegetation and supported beaver populations that constructed dams, which further regulated flows. The beaver were likely in balance with the food supply and predation and may have expanded the areas supporting riparian vegetation (Parker et al. 1985; Skinner 1986).

Past misuse of both watershed sideslopes and associated riparian communities throughout the western USA effectively disrupted the balance between watershed condition and riparian health. A common sequence of events leading to destruction of these upland riparian communities was as follows. Grazing and timber harvesting led to a loss of protective plant cover. When removal was severe, infiltration was reduced and overland flow increased (Leopold 1946; Ellison 1954; Elmore and Beschta 1987). Excessive overland flow delivered more water to the channels, where it exceeded their capacity and enlarged them. This produced expanded drainage networks which maintained rapid runoff that carried large amounts of sediment. When roads and trails were developed as part of this use, overland flow was further concentrated and water delivery to the channels increased. Incised channels drained existing water tables, many of which were close to the surface and supported healthy riparian communities. Lowered water tables led to dewatering, destruction of riparian communities, and an overall reduction in site productivity (Heede 1986). Therefore, the attributes of satisfactory and unsatisfactory watershed condition and riparian health were quite different (Table 1). Concurrently, misuse of lower elevation mainstreams by woodcutting, agricultural development, and urbanization, or more subtle impacts of desiccation from stream incision, impoundment, and channelization, also led to widespread destruction of riparian areas along the large lower elevation rivers throughout the southwestern USA (Conrad and Hutchinson 1985; Minckley and Rinne 1985).

Restoring The Watershed-Riparian Balance

The interrelationship between watershed condition and riparian health is delicately balanced and, consequently, responds readily to both natural processes and human activities (Forsling 1931). Watershed specialists recognized early the need for action programs aimed at rehabilitating these misused and deteriorated watersheds (Forsling 1931; Leopold 1946). This awareness led to widespread implementation of watershed rehabilitation programs throughout the western USA. The objectives of these early projects were to improve plant cover and reduce runoff and erosion by using either revegetation techniques or engineering structures, or both. Implementation of these treatment measures generally reversed the processes

Table 1.—Attributes of satisfactory and unsatisfactory levels of watershed condition and riparian health.

	Satisfactory level		Unsatisfactory level
	Watershed condition		
A	Vegetation and litter cover capable of absorbing precipitation energy, increasing infiltration, and extending release of flow to channels.	A'	Storm energies detach soil, seal soil pores, and create rapid sediment-laden runoff, resulting in ephemeral flows.
B	Minimum drainage density channel network is necessary for conveying runoff from watershed.	B'	Expanding drainage density and channels to accommodate increased surface flow.
C	Maximum temporary storage of water in the watershed system.	C'	Rapid conveyance of water from watershed with minimum retention of water for later release.
D	Limited sediment available in and adjacent to the channel.	D'	Sediment supplied from a variety of upland sources, including sheet erosion and mass erosion from gullies.
	Riparian health		
A	Efficient channel shape with narrow width that conveys all flows less than that of the mean annual peak flow event (2.33 year recurrence) with minimum bank and channel erosion.	A'	Inefficient channel shape often braided or shallow and widely fluctuating. Most events confined in channel. Maximum bank and channel erosion and expanding width.
B	Stream power < critical power.	B'	Stream power > critical power
C	Expanded channel length having lower hydraulic energy gradient and higher sinuosity.	C'	Shortened channel length having higher hydraulic energy gradient and low sinuosity.
D	Narrow, deep, stable channels.	D'	Shallow, wide, unstable channels.
E	Flows above mean annual peak spread over floodplain in low-energy flow: dissipating energy, filtering sediment, and capturing sediment.	E'	Flows contained in channel. Higher velocities associated with flows exceeding mean annual peak. Limited energy dissipation. Full conveyance of sediment and nutrients downstream.
F	Constant log step formation in confined channels. Well-developed meanders in nonconfined channel.	F'	Limited step formation by organic material. Gravel bars or rock structures are primary controls.
G	Channel generally stable with aggrading floodplain.	G'	Channel degrading with infrequent floodplain deposits. Floodplains undermined and eroded.

responsible for originally destroying the balance between riparian areas and the condition of the surrounding watershed. As a result, these treatments provided a new balance in the riparian-watershed system so it could respond to a wider range of storm and streamflow events (oscillations) without producing drastic or permanent changes in the relative balance.

A variety of land treatments and revegetation measures can be applied to deteriorated watersheds to improve hydrologic conditions on watersheds so that riparian communities are stabilized or new ones created. However, proper identification of the causes for degradation and stage of channel evolution is required before different rehabilitation strategies can be developed (Van Haveren and Jackson 1986). General approaches for providing a more stable interrelationship between riparian areas and their surrounding watersheds are based on two general types of actions: (1) improving watershed condition on the sideslopes; and (2) stabilizing channels to reduce erosion. These actions provide the basis for defining and implementing a series of treatments ranging from simple changes in grazing management or revegetation activities to more complex measures involving constructing channel structures that establish base-level controls. A careful analysis of the above treatment alternatives within the framework of cause-and-effect relationships is needed before a rehabilitation program can be implemented (DeBano and Hansen 1989). Problem identification must also include evaluating both land and channel systems as they relate to land-use practices.

Improving Watershed Condition

A first step in restoring an acceptable balance between riparian health and watershed condition is to improve the latter. Riparian rehabilitation should not be attempted in stream systems where watershed condition is unsatisfactory or in a declining trend (Heede 1977; Van Haveren and Jackson 1986). Rehabilitation treatments may be aimed at both improving the vegetation cover on sideslopes and controlling gully erosion in small headwater streams of a watershed. Often, improved management restores plant cover, but the expanded channel network continues to rapidly transmit unfavorable flows and erosion. This demonstrates the importance of rehabilitating the geomorphic slope and surface conditions (i.e., channel shaping) along with improving vegetation cover.

The simplest way of improving watershed condition is to provide plants an opportunity to regain vigor and establish a denser ground cover. Increasing plant cover allows more water to infiltrate into the soil mantle, where it slowly moves downslope into channels. Proper grazing management is the key to improving plant vigor. Where plant cover cannot be improved by grazing management alone, grass seeding and temporary mechanical treatments to retain water and aid in vegetation establishment are viable alternatives. However, these treatments will require several years of rest from grazing so that plants can become well established (root-firm) before grazing is resumed.

Contour trenching has been used with variable success. When properly designed and applied, trenches have been used successfully to improve badly deteriorated high-elevation watersheds in Utah (Bailey et al. 1947; Copeland 1960). In contrast, when rehabilitating steep chaparral watersheds in southern California after a wildfire, trenches could not be designed properly and were found totally ineffective (Rice et al. 1965). In Utah, contour trenches not only reduced peak flows (DeByle 1970a; Doty 1971) but also increased soil moisture storage immediately beneath the treatment depressions (Gifford et al. 1978); however, infiltration rates into trenches varied considerably, depending upon the soil parent material used for constructing the trenches (DeByle 1970b). Reseeding contour trenches with a variety of native and introduced perennial grasses has been found to be an effective means of stabilizing trenches and improving their uptake of water. The best seeding responses are usually obtained in terrace bottoms (Hull 1973). Implementing upstream treatments on watersheds may not necessarily lead to perennial streamflow, but it does provide a method for reducing surface runoff and improving sideslope moisture conditions, which, in turn, contributes to improved watershed condition.

The Role of Channel Treatments in Rehabilitation

Riparian communities in the southwestern USA have been particularly sensitive to overuse because they exist in a semiarid climate and are subjected to wide variations in annual precipitation (Leopold 1946). Perennial surface streamflow frequently does not occur in many smaller drainages throughout the southwestern USA. Marginal streamflow conditions make watersheds and associated riparian areas extremely sensitive to overuse. Any rehabilitation of deteriorated riparian areas is often complex and difficult. In many cases where extensive long-term abuse has occurred, exclusion from grazing and revegetation measures alone may not be sufficient to fully restore former riparian communities. Therefore, additional supplementary measures may be needed, such as the construction of gully structures in upland watersheds (Heede 1968b, 1977). These are often costly and complex but effective means of providing a more stable environment for riparian recovery (Heede and DeBano 1984; Hansen and Kiser 1988; DeBano and Hansen 1989).

An important consideration when designing rehabilitation treatments for upland areas is to be aware of their effect on channel dynamics and to include provisions for maintaining these structures under different channel equilibrium conditions (DeBano and Heede 1987). This is particularly important when riparian restoration depends upon expensive and complex treatments, such as tributary channel structures. Spillway stability and integrity of structures should be checked regularly and appropriate repairs made immediately to weakened or damaged structures. Applying good range management principles in conjunction with channel structures is a prerequisite to long-term success. This requires applying livestock management methods and stocking levels compatible with watershed and riparian improvement objectives as a whole. These approaches have proven vital to the health and success of created riparian communities.

Guidelines for Improving Watershed Condition and Riparian Health

The principles relating to watershed condition and riparian health presented above provide a basis for formulating general management approaches and specific treatment plans necessary for successfully addressing riparian area rehabilitation. This section summarizes the background information presented above within the context of a close interrelationship between riparian health and watershed condition. This synthesis is then used as the basis for developing guidelines to (1) diagnose the causes for disrupting the balance between riparian health and watershed condition; (2) define the objectives for alternative treatments; and (3) specify treatments necessary for restoring an acceptable balance between watershed condition and riparian health.

Various factors, including land uses and misuses, can affect the balance between watershed condition and riparian health by creating (1) excessive runoff, (2) increased frequency and magnitude of peak streamflow, (3) steeper stream slope, (4) excess tributary sediment, and (5) accelerated bank erosion. Substantial misuse of the watershed can destroy the balance between watershed condition and riparian health. Loss of this balance causes a series of adjustments in erosional and depositional processes to occur in the riparian area until a new balance is established. Once achieved, a new balance is maintained until additional changes exceeding the elastic limit of the system occur, setting the process of adjustment in motion again.

After the factors responsible for disrupting the balance between watershed condition and riparian health have been identified, their causes can be used as guiding principles for rehabilitation. These principles can be used for formulating specific treatment objectives and remedies necessary to restore the balance between satisfactory watershed condition and riparian health (Table 2). The large array of possible treatment alternatives discussed above can be classified into two general types, those used for (1) improving vegetation cover and reducing surface runoff and erosion from sidelopes; and (2) stabilizing channel networks. Four broad alternative courses of action arise from these two general approaches. The first alternative is to neither improve sideslope cover nor stabilize the channel. This alternative would usually not be acceptable where riparian-watershed systems are completely out of balance.

The remaining three alternatives require different levels of action programs. A second alternative may involve only managing sideslopes. Sideslope treatment would be feasible on those watersheds where naturally occurring (e.g., bedrock) control sections are present. Natural controls may have been exposed by channel erosion and be currently limiting future downcutting. Under this alternative, if rilling has not occurred, then grazing management alone may allow a dense vegetative cover to become established. Where surface rilling is severe, channel bank shaping, contour trenching, and revegetation may all be required. Techniques for stabilizing channel bank by shaping and revegetation, including use of burlap strips, are described by Heede (1968a, 1975). The primary objective of these treatments is to enhance the natural healing processes, revegetate channel banks, and reduce sediment contributions from bank erosion. It is unlikely riparian communities would be established in response to this treatment alternative.

Table 2.—Conditions threatening riparian areas and possible remedies for achieving different treatment objectives.

Condition	Cause	Remedy	Treatment objective
Excess runoff	Major flood events on pristine watersheds.	None on watershed. If riparian areas have been damaged, then some structures, bank stabilization, and revegetation may be necessary.	Rehabilitate changes.
	Areas with depleted cover lacking infiltration capacity and resistance to surface runoff.	Improve livestock, game, or fire management. Revegetate and manage for increased vegetation and litter cover.	Increased resistance to surface flow. Greater infiltration capacity. Eliminate sheet runoff.
Increased frequency and magnitude of flow events.	Rilled and gullied slopes resulting from depleted cover or soil compaction.	Reduce drainage density by constructing contour furrows or trenches and manage for increased ground cover. Restoration of vegetation.	Increased retention of storm flow on-site until infiltrated. Eliminate concentrated flow. Regulation of runoff through soil mantle. Increase of vegetation cover and improve infiltration.
	Roads and travelways that intercept, collect, and concentrate flows.	Intercept flow paths with waterbars and divert flows to areas with greater infiltration capacity. Rip and reseed compacted surfaces where travelways have been abandoned. Improve forest filter by adding log flow obstructions or detention basins. Eliminate traffic.	Shorten slope length. Infiltrate excess flow into forest floor. Restore on-site infiltration of flow and protect soil. Regulate flows through soil mantle.
Excess discharge	Transbasin diversion that produces the effect of greater drainage area and increased flow.	Provide reservoir storage to regulate transferred flows. Avoid inchannel transport of increased flows. Convey increased flows during low-stage seasons.	Maintain flows within the limits of critical stream power.
	Forest harvest effects on water yield that produce greater runoff.	Schedule harvests in time and space over the watershed to maintain increased runoff within the range of channel capacity and critical power. Consider effects of various silviculture techniques on snow retention and water yield. Minimize road density and drainage of lower slopes by roads.	Maintain flows within critical power threshold. Dissipate peak flows through soil mantle.
Excess stream slope	Channelization of riparian areas by roads, trails, and travelways.	Avoid roads, trails, and travelways in riparian areas. Eliminate old travelways and relocate where necessary. Take special precautions and measures to avoid channelized flow where facilities must be in riparian areas.	Maintain slope, channel length, and configuration that supports dynamic equilibrium. Avoid actions that concentrate flows, produce higher velocities, or change energy configuration of channels or meadows.
	Historic channelized riparian caused by arroyos, gullies, and travelways.	Reestablish and construct channel configuration and slope that watershed conditions can sustain (Heede 1968a) or use check dams to control grade while channel adjusts to new equilibrium. Where conditions allow, consider introducing beaver.	Develop slope channel length and configuration that support a new dynamic equilibrium. Correct conditions that generate unfavorable flows.

Table 2 (continued).—Conditions threatening riparian areas and possible remedies for achieving different treatment objectives.

Condition	Cause	Remedy	Treatment objective
	Absence of large organic debris to provide steps and energy dissipation in confined mountain channels.	Add logs or rock structures to regain stability. Manage adjacent areas to provide a desired rate of logs to the system.	Reduce streamslope with log steps or other structures. Slow velocities, reduce flood peaks, and increase channel uptake. Stabilize sediments.
Excess tributary sediment	Sheet and rill erosion from denuded areas.	Apply techniques similar to those used for controlling excess runoff.	Reduce exposure to erosion. Eliminate concentrated flow on slopes. Provide vegetation protection.
Excess bank sediment	Incised, confined channels that cut high banks.	Improve watershed condition. Reduce bank heights by installing check dams. Use flow separation techniques to deposit materials to buttress banks and provide a media for riparian vegetation establishment. Use techniques outlined for excess slope.	Reduce availability of sediment. Restore channel equilibrium that can be sustained.

A third, more complex, alternative would involve only channel stabilization. This alternative should only be attempted where watersheds are healing naturally, as a result of improvements in watershed condition, but require assistance in stabilizing base control sections. The objective of this treatment could be to stabilize or stop downcutting, reduce erosion, and revegetate channel banks. Channel structures such as check dams or gully plugs would be constructed to control base levels. Dam spacing and effective spillway heights would be designed only to store enough sediment to stabilize the channel. Approaches to gully treatment (Heede 1980), computer procedures for gully control (Heede and Mufich 1974), methods of construction (Heede 1960, 1970), and strategies for determining treatment priorities (Heede 1982) are all available. Water storage and ground water recharge would occur if sufficient annual precipitation were present, and as a result, enhancement of riparian communities would be expected.

Finally, the fourth and most comprehensive treatment alternative would involve both channel stabilization and comprehensive watershed rehabilitation (Heede 1968b, 1977). The objective of this level of treatment would be to stabilize and aggrade channels and provide adequate channel and ground water storage to enhance riparian establishment. Increases in channel deposition and ground water recharge would be accomplished by increasing dam spacing and effective spillway heights. The resulting channel aggradation would provide water storage behind each structure and enhance soil moisture and channel flow. Riparian establishment could occur naturally or be enhanced by the planting of riparian species adapted to the area.

Any combination of the last three levels of action plans described above may be implemented within a single watershed, but it remains critical to establish treatment objectives before implementation. Through the use of comprehensive evaluation and treatment techniques, it is possible to enhance or rehabilitate potential riparian sites throughout the southwestern USA, although the general approach has much wider application. It is important to be aware of the necessity of including continual management and maintenance as an integral part of these rehabilitation plans in order to assure the continued effectiveness of the initial treatments.

Summary and Conclusions

Management of riparian areas is a critical issue throughout the USA. In the southwestern USA, riparian areas are recognized as unique and valuable habitats whose welfare is strongly interrelated with the surrounding watershed. Large-scale misuse of watersheds and associated riparian communities in the 19th century, coupled with emphasis on water yield augmentation in the twentieth century, has led to the degradation of many naturally occurring riparian communities. However, land managers are now recognizing the importance of these valuable upland and riparian ecosystems, and current management philosophy is based on maintaining a viable interrelationship between watershed condition and riparian health.

Land managers are currently implementing a variety of watershed treatments that are, or have the potential for, improving riparian communities. In some cases, these treatments were initiated for reasons other than improving riparian areas but, after being applied, have created a more stable environment and provided favorable hydrologic regimes that allowed riparian communities to become reestablished. The most obvious practices benefiting riparian communities are upstream treatments aimed at improving watershed condition, lengthening duration of streamflow, and stabilizing channels to reduce erosion. Improving watershed condition involves improved livestock management, which is sometimes supplemented by cultural treatments, to gain better livestock distribution and control. In addition, strategically applied mechanical stabilization of channels may become a necessary part of restoration treatment when significant gullying and erosion has occurred in upland tributaries.

Successful treatment programs require a clear picture of the desired riparian and watershed condition. Understanding departures from this desired condition enables managers to select the best combination of improved management and treatments needed to regain riparian health. The basic knowledge for improving watershed and riparian areas is generally available. However, the key to successful rehabilitation lies in wise and timely application of management principles and technology necessary to restore former riparian areas and realize their benefits.

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Use of Hydrology in Riparian Classification

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Abstract.—A concept of "state" is introduced to help deal with units of classification. An approach for better incorporating hydrologic processes into classification systems is presented with emphasis on ground water and its control on the soil water regime. The approach presented requires process understanding on the interactions of soil structure and texture, channel morphology, and hydrology which are described in terms of "hydrologic behaviors". Some examples of viewing classification relative to process-oriented description are given. The approach presented can help managers to better understand the overall complexity and behavior of riparian systems and the potential for riparian sites to progress from one state to another.

Classification has been used as a taxonomical procedure for years in the fields of plant ecology, soil science, zoology, and more recently in wetland/riparian management. Many classification procedures have been developed for use with wetland/riparian vegetation (Brown and Lowe 1973; Cowardin et al. 1979; ; Youngblood et al. 1985; Kovalchik 1987; Platts et al. 1988; Swanson et al. 1988) and at least one for physical attributes (Rosgen 1985). The most recent documents we have examined (most in draft and therefore not cited) attempt to classify vegetation and describe physical attributes together in a narrative-type format (Kovalchik 1987; Platts et al. 1987). Kovalchik's (1987) publication includes a section entitled "Association Descriptions" where narrative descriptions are presented that appear very useful to management. Such narratives include discussions on general location, landforms, soils, floristic characteristics, vegetation ecology, management, and rehabilitation. Within discussions on management and rehabilitation are inferences to site potential, disturbance effects, and rehabilitation pathways.

The newer classification documents we have examined include a great deal of information for management application, rather than just taxonomy. Their appearance is not unlike a typical Soil Conservation Service soils survey document. However, a deficiency area within the riparian classification documents examined, is a lack of specific description on the hydrologic and geomorphic processes largely responsible for a site's environment. This paper presents an approach in viewing riparian systems and suggests some standard types of hydrologic description to be included in the narrative products of classification documents.

States of the System

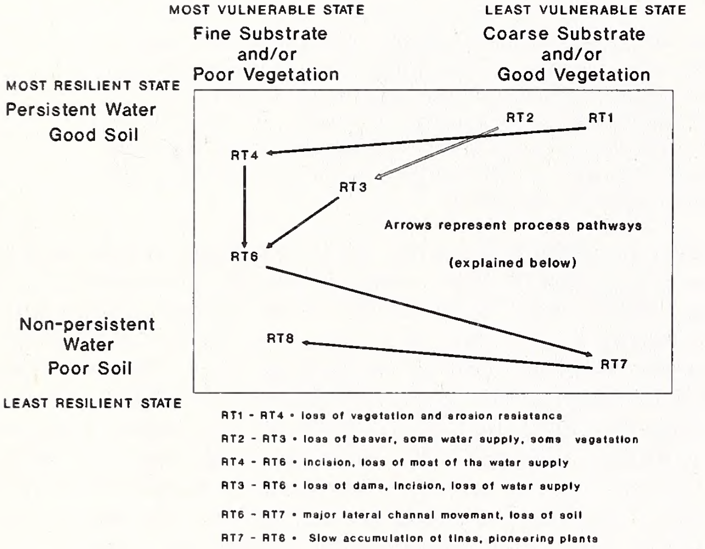
In a riparian system, environmental conditions are not stable. The likelihood of soil and water environmental conditions at many riparian sites remaining stable, over several decades or even years, is remote. For example, fine sediment may be deposited over gravel (aggradation) creating a new soil or substrate with different profiles, permeabilities, and other soil moisture characteristics. Other sites may be eroded or in some manner have their soil structure or water supplies altered. Therefore, a riparian site may change with time (Figure 1) from one defined riparian type to another through aggradation or degradation of the site or through major change of the water supply to the site. The possible range of riparian types for a site within a larger riparian system may be depicted graphically; sites are referred to as "states" of the site, akin to a vegetation classifiers' community type (Figure 1). We have chosen to use the general term state, rather than other units commonly used in riparian/stream classification, to reduce confusion in terminology. State is a flexible unit and can represent many types of classification units as required by the user.

The state represents the likely appearance of a riparian site based on various environmental conditions. In describing states in this paper, we chose to express environmental conditions in terms of erosion resistance and soil water. Soil water is described, in general, by the persistence of the source of soil water and/or the ability of the soil to hold and release moisture to vegetation. Erosion resistance is described by vegetation condition (as it relates to soil and substrate stability) and substrate texture. Obviously, many factors could describe soil water and erosion resistance. We used those factors thought to be most useful in considering hydrologic processes and in developing an understanding of a site's behavior.

Process Pathways

If arrows are used to represent the process responsible for a state change, the process pathways are a description

Figure 1.—Concept of state, state change, and process pathways. States shown as riparian type (RT1-8). Each state represents a potential environment for a site that is spatially fixed. State RT1 could represent an active, ecologically well-balanced valley depositional. It is not considered vulnerable because of dense willow cover. State RT2 could represent a ecologically well-balance beaver dominated system. Its environmental condition it is not too vulnerable to change since the beaver/vegetation combination offers good protection and excellent recovery potential from most environmentally altering conditions. RT3 could represent a remnant of RT2 without the beaver. It is still resilient but is highly vulnerable to further change. Loss of dams is probable. State RT4 is a stressed, possibly overgrazed condition of RT1. Its resiliency is high; however, its vulnerability is much lower because of the reduction in willow cover. State RT5 is the beginning of incisement phase of RT6, but there are significant amounts of vegetation and substrate remaining. RT6 represents major entrenchment. Soil water regime is severely altered. Bank vegetation no longer will survive. State RT7 is the most severe change resulting from lateral channel migration. It is no longer considered vulnerable since the site has changed to very coarse channel material. Recovery to state RT8 is slow without assistance from the beaver or other structural means.


MOST VULNERABLE STATE
Fine Substrate and/or Poor Vegetation
LEAST VULNERABLE STATE
Coarse Substrate and/or Good Vegetation
MOST RESILIENT STATE
Persistent Water Good Soil
Non-persistent Water Poor Soil
LEAST RESILIENT STATE
RT2
RT1
RT4
RT3
RT6
RT8
RT7
Arrows represent process pathways
(explained below)
RT1 - RT4 • loss of vegetation and erosion resistance
RT2 - RT3 • loss of beaver, some water supply, some vegetation
RT4 - RT6 • incision, loss of most of the water supply
RT3 - RT6 • loss of dams, incision, loss of water supply
RT6 - RT7 • major lateral channel movement, loss of soil
RT7 - RT8 • Slow accumulation of fines, pioneering plants

of hydrologic process mechanisms responsible for the change (Figure 1). The cause of the change at this point in the description is not considered; rather, the understanding of the process mechanisms is the main concern. After process pathways are identified they can be related to potential causes of the change. For example, a process pathway may be the change in ground-water gradient because of channel deepening. Subsequent determination of potential causes of the deepening can be worked into the site description or other management guidance.

Incorporating the Hydrologic Processes

As discussed above, we believe a riparian classification and/or site description should include sufficient process information to help determine cause and effect as well as management options. We suggest as a minimum, the following information be included in the classification description (details are given later):

(1.) Description of substrates and soil (streambank, channel bottom, and floodplain), including profile descriptions and erosion resistance.

(2.) Relation of various discharge amounts to channel capacity and function.

(3.) Description of the general flow regime during the year, including the type of source, persistence, and other behaviors thought to be important.

(4.) Description of ground and surface water behaviors typically encountered on the site through its range of states.

The following sections expand the four recommended subjects for inclusion in a riparian classification site description. An example site description follows these sections. The section "Hydrologic and Geomorphic Concepts" presents some basic discussion that may be helpful in identifying behaviors and developing narrative description. It is important that the narrative be as relative (not absolute) as possible to the general nature of the site, particularly in discussion of flows, to allow more meaningful extrapolation to similar areas (e.g., discharge as it relates to the position of the water column in channel, rather than a discharge rate).

Substrates and Soils

In this paper, substrate is defined as rock and soil material that resides within the riparian site, channel bed, and banks. Soils refers to the surface two-meters or so of substrate that is generally capable of supporting vegetative growth. Descriptions should include:

(1.) A graphic of the basic cross-section of valley (normal to the valley) including estimated layering of substrates and general texture where definable, particularly about three meters above and two meters below the existing channel bottom.

(2.) Information on bank composition and structure (e.g. cohesive, noncohesive, composite).

(3.) Estimated potential effectiveness of vegetation in controlling erosion on the banks and floodplain.

Discharge and Channel Capacity

Channel capacity as discussed in this paper refers to the position of water stage (i.e., surface water elevation) in the channel at various discharges. A totally full channel is called bankfull. Discharge at or above bankfull capacity assumes overbank flow (flow on floodplain). Descriptions should include typical position of water stage in the representative channel cross-sections for discharges equivalent to one-year, three-year, five-year, ten-year, and fifty-year flood occurrence and average annual minimum flow.

Flow regime

The flow regime description should include a representation of streamflow throughout the year including average and extreme conditions and the likely behaviors that control them. Descriptions should include:

(1.) Typical periods and explanations of extremes should be given (e.g. winter rain on frozen ground, late summer rain on hydrophobic soils).

(2.) Sources of the water and their persistence should be described in terms of where the source(s) originates (i.e., within or outside of the riparian system) and their distribution or concentration relative to the stream (i.e., discrete as in springs, geysers, seeps, or lateral as in seepage sources along the stream). Persistence of the sources is described in terms of their capability to provide water throughout a growing season or beyond. Other behaviors should be described such as reservoir operation and man-induced or unusual flow modifications.

Surface and Ground-Water Behavior

These are descriptions of the behaviors responsible for the soil water characteristics of the sites and their states. These may include ground-water energy gradients; capillarity, surface, and subsurface hydraulic controls; channel, bank, and floodplain interaction; and water-holding capacity of substrate. Process explanations are presented later.

Example Application

The above recommended information is an ideal request. It is very difficult to determine many of the descriptions with certainty, and we are not suggesting that field investigators spend an inordinate amount of time or money completing a description. However, we are convinced that experienced investigators can make estimates that are reasonably accurate, commensurate with the accuracy of most classification efforts, that will give the user hydrologic process information and a clearer understanding of how and why a riparian system operates.

The following example presents what might appear in a riparian classification description that has been integrated with hydrologic process information.

Riparian Site Description (Example)

The following example presents a lot of information, much of which is directed towards management. Obviously, descriptions could be expanded in subject areas of particular importance.

Riparian type name.—Quaking Aspen/Willow Type — Fluvial Canyon, Depositional

Location and landform.—Elevation range of 1200 through 2100 m. Typically occurs alluvial and colluvial surfaces adjacent to streams.

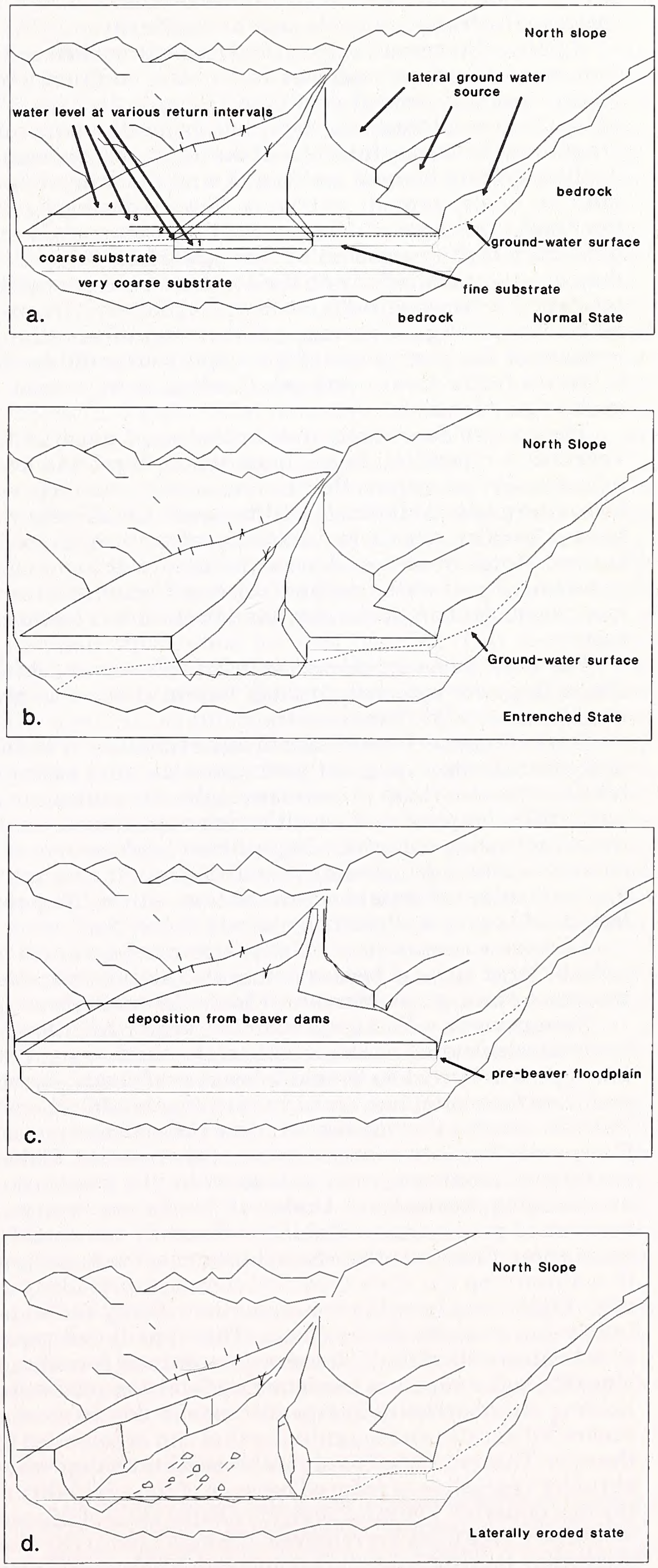
Stream type.—Closely represented by a B4 stream type (Rosgen 1985). Gradients typically near 2%, sinuosity between 1.5 and 1.9, channel material gravels, sands, some cobble. Upper bank, fine cohesive. Narrow and deep channel, well to moderately confined (Figure 2a).

Vegetation.—This type is dominated by a quaking aspen *Populus tremuloides* overstory and an understory of dense willow *Salix* spp. and other shrubs. Graminoids include bluejoint wheatgrass *Agropyron* sp., Kentucky bluegrass *Poa pratensis*, fowl mannagrass *Glyceria* sp. Diverse forbs may be present, including northern bedstraw *Galium* sp., common horsetail *Equisetum arvense*. Seral stages can include much reduced density and reproduction of quaking aspen and shrubs due to heavy grazing.

Soil.—Soils are usually fine-grained overlying coarser cobbles, gravel, and sand. Upper layers range from well-sorted clay soil to a mixture of gravel and fine grained material. Typically the fine-grained soil thickness is less than 1 m.

Water Regime.—Most precipitation occurs in the winter and accumulates as snowpack, particularly on the northern slopes due to topographical location and vegetation. Average annual floods and larger floods associated with more controlled snowpack melt or rain can be affected by the amount of vegetation cover on the watershed. Based on current channel geometry measurement, average floods are in the range of 1.6 $m^3/s/km^2$. Most sites are characterized by local, lateral, and persistent (easily lasts a growing season) inflow on north slopes. This is due to a large accumulation of fine material providing sufficient storage to capture much of the winter snowpack. South slopes

Figure 2.—(a) quaking aspen/willow type — Fluvial Canyon, Depositional State, typical cross-section. Approximate stage with minimum flow (1) and three (2), ten (3), and 50-year (4) flood return interval is shown. (b) entrenched state, (c) beaver dominated state, (d) laterally eroded state.



rarely have persistent inflow. Soil moisture on the northern side of the channel is maintained mostly by ground-water flow gradients towards the stream with some effective capillarity near the northern stream bank. Soil moisture on the southern stream bank is maintained almost exclusively from longitudinal gradients accentuated by instream hydraulic controls and/or capillarity.

States.—Common states include an entrenched condition, beaver *Castor canadensis* dominated condition, and a severe, laterally eroded condition (Figures 2b - 2d). The entrenched condition will vary, but generally as normal stage drops below the interface of the fine/coarse material, capillarity may become ineffective, and the annual flood may no longer provide overbank flows reducing bank/floodplain recharge efficiency. Severely entrenched systems may lead to removal of fine materials. Vegetation may change, particularly on the southern bank, to species tolerating drier conditions, such as sagebrush, *Artemsia* sp. North-side vegetation may not show significant change because of the persistence of the water source unless disturbance factor from overbank flooding is important in species propagation.

The beaver dominated state will change much of the vegetation character to an open water type and may aggrade several meters. Post-beaver stream channels will have fine-grained channels and terraces. Capillarity will have a greater role in maintenance of soil-water levels. Incised states of beaver dominated sites will have more pronounced soil-water decline since soil-water source is more dependent on the stream than in the lower elevation states.

The most severely altered state of this site would be where fines are removed, through lateral channel migration, leaving only coarse substrate.

State change.—Loss or significant reduction in willow and other shrub cover greatly increases the sites susceptibility to incision. Loss of instream hydraulic controls (e.g. pool/riffle complex) may result in drier upperbank conditions, increasing potential of significant bank erosion and channel widening, including lateral migration. Change to beaver dominated state is almost certain with viable populations of beaver and adequate woody vegetation.

Adjacent communities.—Wetter sites are dominated by sedges *Carex* sp. (e.g. beaver dominated state), drier sites by spruce *Picea* sp., sagebrush, or Idaho fescue *Festuca* sp.

Management.—Forage production varies from low to moderate depending on the density of the shrub layer. This site type is preferred by livestock because of shade, shrubs and trees for scratching, and a variety of palatable species. Wildlife use can include beaver, deer *Odocoileus* spp., elk *Cervus elaphus*, and a large number of bird species. Fisheries habitat is often greatly enhanced by the presence of overhanging vegetation. Undercut banks are common because of the increased stability offered by the shrubby vegetation. Fire and other disturbance may be important in maintaining the site's type. Soil compaction is likely on site. Trails may provide concentration points for water increasing chances for headcuts. This type is not considered vulnerable while in dense vegetation and is resilient, since the water supply is persistent and soil has good water holding characteristics and is adequate in depth (erosion occurs but at rates and magnitudes that can be tolerated by the site). This type is very vulnerable to state change when shrubby vegetation is reduced because of the erodibility of the fine material. The most severely altered state of this site would be where fines are removed, through lateral channel migration, leaving only coarse substrate. The water source, though persistent, would have poor quality soil and recovery from this altered state would be very slow without assistance from beavers or artificial means.

Hydrologic and Geomorphic Concepts

Some hydrologic and geomorphic concepts are presented along with specific ground water behaviors that may be helpful in preparing a hydrologic description for riparian classification purposes. This section is included as a summary of what we consider are important processes and behaviors. Some of the information is well-known basic knowledge, some are based on extensive research, and some are based solely on the observations of the authors.

Water Regime and Influence of Riparian Systems

The flow regime controls the forces governing the appearance and water supply of most riparian systems. The stream's flow regime affects the water supply in other parts of the riparian system. In particular, the flow regime interacts with the floodplain substrate and vegetation. Flow regime is usually described in terms of magnitude, duration, and frequency of streamflow. Both the infrequent, extreme events and the more frequent, less extreme events shape the riparian system, but in very different ways. Wolman and Miller (1960) pointed out that, although extreme events may play an important role in shaping some floodplains, it is the less extreme and more frequent flooding events (considered as bankfull) that probably are most influential.

The supply of water is controlled by precipitation and regulated through interactions among geology, soils, and vegetation. Precipitation on impermeable soil and bedrock will enter the channel system rapidly. Conversely, precipitation on permeable, well-vegetated soil will enter a ground-water system and may not reach a stream channel for many seasons. Recognizing the dominant characteristics of the watershed and riparian system can help identify the processes controlling the rates at which water is released and captured by the system. This can lead to understanding the range of effects that management may impart.

Floodplain and Channel Interaction

One way the floodplain and stream channel interact is through temporary water storage in the streambanks that can affect normal and high flows. Water storage is significant enough to reduce flood peaks in some cases (Freeze and Cherry 1979). Cooper and Rorabaugh (1963) developed a number of solutions to inflow and outflow between banks. Freeze (1972), Kraeger-Rovey (1975), and Vasiliev (1987) have developed interrelated mathematical models that incorporate bank storage and streamflow interaction. Although extreme highs may have a totally different effect than more frequent flood events, any event that results in over-bank flooding affects the floodplain. Low stage flows also affect the floodplain through direct use of bank storage in maintaining low flows.

Another way that the channel and adjacent floodplain interact is through the rate and magnitude of stored water available for soil-water and vegetation. The shape, size, roughness, and gradient of the channel determine the depth of water in the channel. Assuming a constant volume of water, the water column (stage) will be higher when confined in a narrow channel than when spread out over a wide channel (Figure 3). Compared to a wide channel, streamflow confined in narrow channels has a higher stage, resulting in a higher hydraulic potential, increasing rates of exchange between the channel and banks, beneath and sometimes above the floodplain (Figure 3). This becomes important when describing the affects of incisement on soil-water regime. Channels that widen or deepen have enlarged capacities, reducing the number of overbank events and further limiting the interaction with the floodplain and reducing soil moisture through reduction in stream stage. These are all hydrologic processes and behaviors that may affect state change.

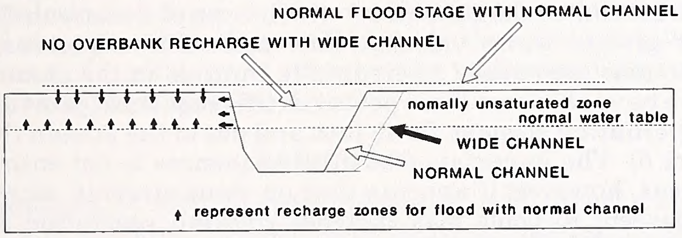

NORMAL FLOOD STAGE WITH NORMAL CHANNEL
NO OVERBANK RECHARGE WITH WIDE CHANNEL
nomally unsaturated zone
normal water table
WIDE CHANNEL
NORMAL CHANNEL
represent recharge zones for flood with normal channel

Figure 3.—Floodplain and channel interaction as regulated by channel shape. Normal channel increases potential for floodplain recharge compared to enlarged channel.

Floodplain development.—The basic mechanism for building the floodplains, according to Wolman and Leopold (1956), appears to be the lateral migration or progression of the point bars rather then the fine sediment deposited during the overbank flow. Subsequent flooding then overtops and perhaps backfills the natural levees resulting in somewhat of a level surface. Over a long period of time, these bars continue to migrate within the confines of the valley walls. They found that the lateral channel migration was the result of frequent, one to two year events, and not so much the major, infrequent events. Important findings in Wolman and Leopold (1956) are: channels generally overtop their banks every year or every other year, floodplain materials may not be very homogeneous because of lateral accretion, and bank erosion is to be expected annually. This may help explain the variations and complexes seen by the vegetation mapper.

Vegetation and channel shape.—Vegetation establishing on new sediment deposits acts as both an internal binder, holding the soil together, and as a boundary layer control, increasing resistance to flowing water. These actions, coupled with point bar progression, help reduce water flow and stabilize newly deposited material. The degree to which vegetation controls channel shape depends on its ability to improve the inherent substrate stability. The frequency of channel-forming discharge events and the establishment time of the roots of some plant species, are both about one to three years, and may therefore compliment each other (we have seen dozens of sites where cottonwood *Populus* spp. and willow establish and grow up to a foot in one year). Numerous researchers have documented changes in channel geometry after vegetation loss. A recent study (Hey and Thorne 1986) showed that stream width, in particular, appeared to be very dependent on vegetation. Rivers with grass banks were wider than rivers with more abundant shrub and tree species. Another common example in the western USA is when the carrying capacity of the channel increases, and the bankfull discharge recurrence interval changes from one to two years to five or more years. We have observed vegetation encroachment on channels below hydroelectric developments due probably to a decrease in the flooding events.

Colluvial and other direct deposits into floodplain.—Hillslope erosion and mass wasting provide material for the stream to use in creating a floodplain and also may detain flood waters by creating a hydraulic control or a dam. The rate and frequency of events can be accelerated by management. The substrate derived from such direct deposits vary. Obviously, direct deposits may be very significant in their influence on the substrate for riparian vegetation.

Large woody debris.—Large woody debris may have roles in modifying flood flows, particularly where gradients and substrate limit the effectiveness or establishment of wetland vegetation. The presence of large woody debris in low order drainages may help reduce the size of peak flows in recipient drainages. In some riparian systems where substrate may not be bedrock controlled, the long-term supply of large woody debris into the system is necessary to prevent substantial degradation and maintain hydraulic diversity (i.e. pools, riffles).

Beavers.—In many riparian systems that we have visited in the Western USA, beaver populations have been largely responsible for the establishment of the floodplain. It is common knowledge that beaver dams act functionally as detention basins and, as such, can trap a tremendous amount of material. As with many natural systems, a dynamic equilibrium between beavers, their food supply, dam material supply, and predators must exist for long-term stability of the riparian system; problems arise when the dynamic equilibrium is altered. Howard and Larson (1985) developed some prediction techniques for estimating active colony density that consider vegetation type and amount, watershed size, stream width, stream gradient, and substrate permeability. In our observations on a dozen beaver-dominated systems, the frequent flood event appears to do little to functioning beaver systems, and larger less frequent flood events may not cause more than some localized degradation. This lack of system degradation is probably attributable to the continuous presence of the beaver providing a consistent, rapid, and adaptable stream control. Loss of beaver without adequate vegetation reestablishment prior to a flood occurrence can result in a very primitive, degraded channel. Bergstrom (1985) presents a good overview of beaver ecology.

Maintenance of the channel and floodplain.—Channel maintenance flows can be thought of as flows with sufficient velocities to remove or move sediment through the system to maintain bankfull carrying capacity (of the one to three-year flood) but not causing unacceptable degradation to the channel. A basis for determining and incorporating channel maintenance flows can be found in Rosgen et al. (1986).

Floodplain maintenance requires that the floodplain function in the storage and release of flood water. Maintenance of good stage levels and bankfull flows are critical for a functional floodplain and are closely interrelated to the type and amount of vegetation cover.

Groundwater Terminology and Behavior

The following ground-water terms and behaviors can be used in developing a description for use in a classification.

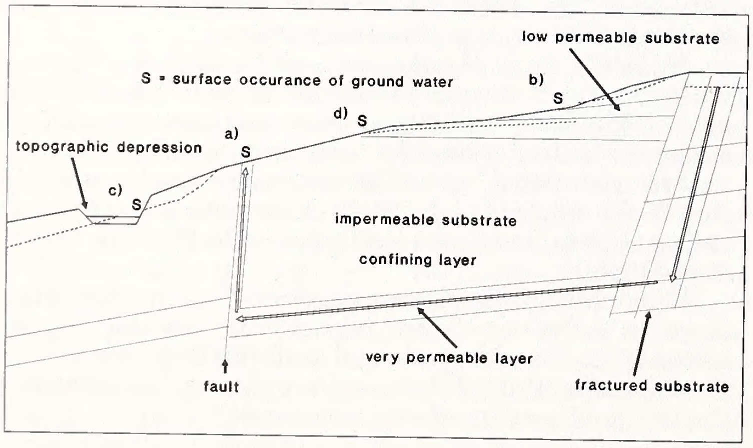
Source supply and persistence.—Supply and storage capacity are the major regulators in ground water. Supply, or recharge, can occur directly from precipitation or from other surface and ground water sources. Ground-water systems can be described as regional, intermediate, or local. In a very large regional system, the only recharge source is precipitation although a network of local and intermediate systems may redistribute the water. Flow remains steady because of the large storage capacity and areas of contribution. Intermediate systems are basin or drainage dependent but may be large enough to persist for more than one season without recharge. They contain local systems and may have some exchange with other intermediate systems. Local systems are small and dependent on seasonal precipitation, usually requiring recharge after one season. An area with abundant small and intermediate systems is likely to be topographically diverse. Areas with few small and intermediate systems are likely to be flat. Persistence of the sources is described in terms of their size and capability to provide water throughout a growing season or beyond.

Source type.—Sources of water for riparian systems are defined as discrete or lateral. An example of a lateral source is bank seepage along a stream where the water table is above the stage of the stream. A discrete source is from defined and localized areas such as springs, geysers, or seeps.

Source dependence.—Sources of water are also considered system dependent or system independent. System dependent means that the water source is from the upstream riparian system. System independent means the source is largely independent from the immediate riparian network.

Rate and direction of flow.—Ground-water flow is predominately regulated by the permeability of the substrate, travel distance, and the difference in hydrostatic pressure (head, gradient). Fine texture material will transmit water quite slowly (clayey substrate < 0.1 cm/h) when compared to coarse textured material (sand > 20 cm/h) at a given head. The direction of ground-water flow is regulated by the alignment of the pores and cracks, the change of the substrates permeability, and hydrostatic pressure (Figure 4).

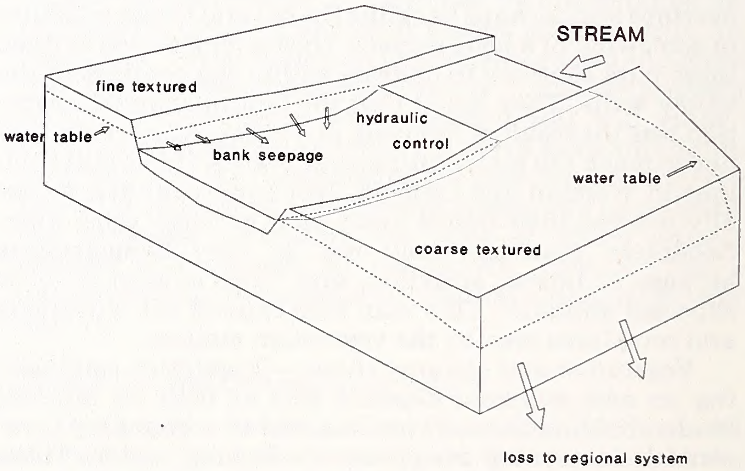
Figure 4.—Various ground-water behaviors from: (a) confining layer, (b) change in hydraulic property of substrate, (c) topographic depression, and (d) subsurface dam, all resulting in surface appearance of ground water.



Channel permeability.—Channel permeability controls the rate of loss and gain of flow within the channel. A channel can be highly permeable or very impermeable depending on the texture of the substrate. A highly permeable substrate in a fines-limited system may prevent significant soil water accumulation in the banks or water table development adjacent to a stream. Some silty channels are very impermeable to loss of flow, but are more permeable to receiving flow (Kraeger-Rovey 1975). We have observed some channels that look as though they should have very permeable substrate but on closer examination appear to exhibit a chemical cementing of interstitial pores that reduces permeability. The importance of the channel in regulating water supplies should not be overlooked.

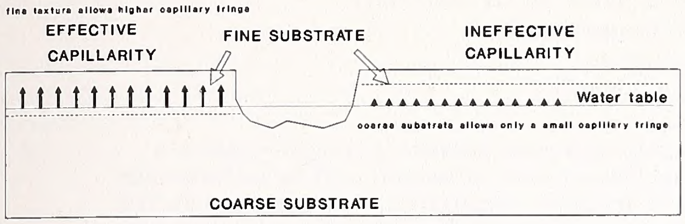
Active-inactive floodplain.—If the one- to three-year flood reaches bankfull capacity, the floodplain is considered "active". Floodplains become active or inactive through channel change or through changes in annual flood frequency (i.e. upland watershed condition). Floodplains become inactive as channel dimensions increase, and the one- to three-year flood cannot reach overtop the bank. While these conditions may be transitional, they can have a significant effect on the soil-water regime and vegetation. Hydraulic control refers to any number of types of structural or channel forms which control the streamflow or ground water velocity. Pool and riffle sequences in streams are caused by hydraulic controls in the channel. We have observed these pool and riffle sequences providing alternating seepage flows into and out of the stream (Figure 5). The importance of these sequences is not entirely clear, however; it appears that on some streams, storage adjacent to pools may increase riparian vegetation and extend the period of flow.

Figure 5.—Local effect of pool and riffle on bank/floodplain water storage and release.



Effective capillarity.—The height of capillary rise is primarily determined by soil texture (fine texture = higher rise). Where capillarity is important for maintaining soil moisture in the upper soil layers and it is occurring, it is termed effective capillarity. If it is not occurring, it is termed ineffective capillarity. The effectiveness of capillary rise (Figure 6) is determined by the position of the saturated zone and by soil layering (e.g. capillary action can draw soil water up from coarse soil pore spaces into finer pore spaces but not from fine into coarse). Where coarse substrate (having little or no capillary rise potential) underlies the finer substrate, water levels must at least reach the interface of the fine and coarse material for capillary rise to occur, and often reach above the interface for capillarity to remain effective through the growing season.

Figure 6.—Effective and ineffective capillarity due to location of coarse/fine substrate interface and water table.


fine texture allows higher capillary fringe
EFFECTIVE CAPILLARITY
FINE SUBSTRATE
INEFFECTIVE CAPILLARITY
Water table
coarse substrate allows only a small capillary fringe
COARSE SUBSTRATE

Conclusion

Riparian classification and site description can be improved if the investigator conducting the classification can define the processes important to the system's existence. We have presented several ideas for integrating this process information and some insights on the interaction of hydrologic processes. We hope that future investigation and classification efforts will identify the roles and interactions of hydrology to improve the understanding and management of riparian systems.

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Nutrient Cycling at the Land-Water Interface: the Importance of the Riparian Zone[1]

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Abstract.—Riparian ecosystems are sites of important biogeochemical processes that affect the composition and structure of the streamside biota as well as aquatic systems. Microbial activity, coupled with the slow diffusion of oxygen in waterlogged riparian soils, causes anaerobic conditions and reduction in reduction-oxidation (redox) potential. Redox potentials provide a useful measurement as to the intensity of anaerobic conditions and the degree of chemical transformation in riparian zones. Under anaerobic conditions, biogeochemical cycles differ greatly from the aerobic conditions of surrounding uplands. Different plant species are adapted to survive in varying levels of reduced waterlogged conditions such that different plant communities occupy sites of different redox potential. For example, Kentucky bluegrass *Poa pratensis*-timothy *Phleum pratense* communities occurred in areas of high redox potential (well drained soils) (570 mV), beaked sedge *Carex rostrata* in moderate redox potential (-48 mV), and tall mannagrass *Glyceria grandis* (-164 mV) in waterlogged, anaerobic soils. Recent research has shown that low redox potentials result in denitrification and that phosphorus immobilization processes occur within intact riparian ecosystems, thereby greatly influencing water quality. The effects of grazing or other anthropogenic disturbances can alter these biogeochemical cycles resulting in drastic alterations in riparian vegetation composition and productivity, aquatic ecosystems, and water quality. Given these important linkages to resource productivity, the effect of land use activities on biogeochemical cycles of riparian/stream ecosystems should be considered.

Riparian ecosystems perform a variety of functions essential to a healthy instream community and high water quality (Swanson et al. 1982). Brinson et al. (1981) estimated that over 70% of riparian communities have been altered and less than 2% of the land area in the USA consists of intact natural riparian communities. Major losses of riparian bottom land forest have occurred as a result of lumbering, drainage for agriculture (Korte and Fredrickson 1977; McGill 1979) or channelization (Funk and Robinson 1974; Barclay 1978; Triska et al. 1982). Historical activities such as debris removal, beaver *Castor canadensis* trapping, and grazing reduced the biological integrity of riparian zones before extensive research began (Harman et al. 1986; Naiman et al. 1986). These changes have greatly altered riparian ecosystem structure and function thereby greatly changing biotic interrelationships between riparian and aquatic ecosystems.

Livestock are believed to be attracted to riparian areas by the availability of water, shade, thermal cover, and quality and quantity of forage (Kauffman and Krueger 1984). Although riparian meadows occupy only 1-2% of the interior northwestern USA, they account for 81% of the forage removed by livestock (Roath and Krueger 1982). In reviewing livestock-riparian relationships, Kauffman (1988), separated the impacts of excessive grazing in the riparian zone into four components: (1) compaction of soils which increases runoff and decreases water availability to plants, (2) herbage removal which lowers plant vigor and changes competitive interactions among species, (3) physical damage to vegetation by rubbing, trampling, and browsing, and (4) changes in fluvial processes which may lower water tables and/or cause a decline in invasion sites for woody species.

Dahm et al. (1987) have concluded that human influences (beaver trapping, channelization, and grazing) have acted to uncouple riparian and stream ecosystem interactions. This has important implications as riparian zones are physical, biological, and chemical links between terrestrial and aquatic environments. Important, yet little studied ecological processes of riparian zones are the biogeochemical cycles that influence both riparian and aquatic systems. Riparian areas are unique in that they contain large areas of anaerobic (saturated) soil. In saturated soils, measurement of reduction-oxidation (redox) potential provides a useful indicator of the intensity of anaerobic conditions and therefore the degree of chemical transformation and the biogeochemical pathway operating in the riparian zone.

Nutrient inputs resulting from the biogeochemical processes of riparian zones not only affect the associated aquatic community, but also the downstream industrial, recreational, and agricultural water users as well (Coats et al. 1976; Rhodes et al. 1985). Pristine or intact riparian zones have been found to function as important sites for denitrification (Coats et al. 1976; Lowrance et al 1984; Jacobs and Gilliam 1985). Additionally, riparian zones are important phosphorus sinks where phosphorus adsorbed to clay particles is deposited during high flow or trapped in runoff from surrounding uplands allowing time for plant uptake or microbial use (Yarbro 1979; Cooper and Gilliam 1987; Cooper et al. 1987). Given the critical role biogeochemical cycles play in riparian ecosystem structure and function, management strategies will need to be designed to insure these ecosystems are functioning in a dynamic equilibrium.

Methods

The data presented in this paper are from ongoing studies of the Catherine Creek riparian ecosystems. This research area is located in the foothills of the Wallowa Mountains of northeastern Oregon. Catherine Creek is a third order tributary of the Grande Ronde River, average discharge is 3.4m^3/sec (USGS 1981) and peak flows usually occur from April to early June. Elevation of the study area is approximately 1030 m, and mean precipitation is 60 cm, the majority of which occurs as snow during the winter months.

Research in the Catherine Creek riparian zone has been conducted since 1978. Kauffman (1982) subjectively identified a total of 256 stands of vegetation representing 60 discrete plant communities. Livestock impacts on plant communities and streambanks were reported by Kauffman et al (1983a,b).

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[1] Technical Paper No. 8724, Oregon Agricultural Experiment Station, Corvallis.

In four riparian plant communities we measured redox potential using platinum probes that were constructed using the methods of Mueller et al. (1985). Salt bridges (Veneman and Pickering 1983) were used to facilitate measurements when the upper soil layers were dry. Millivolts were read using a Beckman pH meter.

Importance of Riparian Areas

Streamside vegetation is a major source of energy and nutrients for instream communities. Cummins and Spengler (1978) estimated that 90% of the organic matter supporting headwater (first order) stream communities was of terrestrial origin. In these small streams of forested ecosystems, up to 99% of the energy input may be from allochthonous sources, and 1% is derived from instream (autochthonous) sources (Cummins 1974).

Riparian vegetation reduces the velocity and erosive energy of overbank flow (Li and Shen 1973; Petryk and Bosmajian 1975). Reduction of water velocity allows the riparian zone to function as a site of sediment deposition, trapping sediments that would otherwise degrade fish habitat and water quality (Meehan et al. 1977; Cooper et al. 1987). Cooper et al. (1987) found that riparian woodlands bordering agricultural fields in North Carolina trapped 84-90% of the sediment transported from these fields. This same riparian zone was found by Cooper and Gilliam (1987) to retain 50% of the phosphorus leaving agricultural fields. Yarbro (1979) found the sediments of a North Carolina stream trapped 1.7 kg/hectare of phosphorus.

Overhanging riparian vegetation moderates the thermal regime of aquatic communities by providing cooler instream temperatures (Meehan et al. 1977; Swanson et al. 1982). Removal of riparian vegetation can result in increases of water temperatures and decreases in levels of dissolved oxygen and carbon dioxide (Brown 1983). Warm water is conducive to algal and bacterial growth including bacterial species pathogenic to fish (Brett 1956). Less oxygen available for aerobic life processes will reduce populations of heterotrophs, increasing the amount of nutrients exported from the watershed.

Unlike upland areas, soils of riparian zones can be saturated throughout the year because of their low position on the landscape and close proximity to water. Even during periods of summer base flow, the deeper soil horizons remain saturated. Under saturated conditions the demand for oxygen exceeds the supply and anaerobic conditions develop in the soil profile. Anaerobiosis is not uniform throughout a submerged riparian soil profile (Patrick and DeLaune 1972; Ponnamperuma 1972). A thin oxidized layer at the soil-water interface results from the diffusion of oxygen from water or the atmosphere into the soil. The depth of this aerobic layer ranges from a few millimeters to a few centimeters and is controlled by the oxygen demand of the soil microorganisms (Gambrell and Patrick 1978). This aerobic layer is of tremendous significance with respect to nutrient cycling. This is a small refuge of aerobic bacteria. These bacteria are responsible for nitrification processes (conversion of ammonium to nitrate). This form of nitrogen is soluble and negatively charged and therefore subject to leaching or denitrification in the anaerobic layer. Redox potentials can provide a useful measurement of the intensity of anaerobic conditions and therefore the degree of chemical transformation in riparian zones.

Effects of Redox Potential on Nutrients

Redox potential is a measure of electron availability in chemical and biological systems (Mitsch and Gosselink 1986). Redox potential can provide a relative measure of the availability of certain nutrients and chemical conditions in saturated soils (Table 1). The reduced form of many elements, such as iron, manganese, and sulfide, can be toxic to plants and occur under conditions of low redox potential. Chemical reactions such as denitrification also occur under low redox potential and have a direct effect on water quality. Low redox potentials (200 to -400 mV) are associated with reduced, submerged soils. Well oxidized soils have redox potentials of about 300 to 800 mV (Ponnamperuma 1972). Turner and Patrick (1968) found that when soil oxygen was at a level of 4%, redox potential began to decrease sharply. Much of this drop in redox potential results from increasing populations of anaerobic bacteria which use inorganic compounds such as nitrate-nitrogen as terminal electron acceptors (Brock et al. 1984). This reduction and use of nitrate-nitrogen as a terminal electron acceptor is termed denitrification. Denitrification plays a major role in water quality by removing nitrate-nitrogen from the riparian system and converting it to gaseous forms.

Reduction of nutrients occurs in a predictable pattern as redox decreases (Table 1). This process begins within a few hours to a few days after waterlogged conditions occur depending upon soil temperature and organic matter content (Glinski and Stepniewski 1985). Warm spring temperatures, high amounts of organic matter, water saturation, and rapid microbial growth will result in rapid declines in redox potential (Meek and Stolzy 1978). After waterlogged conditions occur in the spring or winter, oxygen is rapidly depleted by aerobic microorganisms. Oxygen is undetectable at a redox potential below the range of 320 to 340 mV (Gambrell and Patrick 1978).

Redox potential decreases as obligate and facultative anaerobic microorganisms begin to utilize nitrate-nitrogen as a terminal electron acceptor during the process of respiration. Denitrification occurs at about 230 mV (Gambrell and Patrick 1978). Denitrification in riparian zones can be important for maintenance of high water quality. Rhodes

Table 1.—Oxidized and reduced forms of several elements and approximate redox potentials for transformation. (From Mitsch and Goselink 1986.)

Element	Oxidized form		Reduced form		Redox potential (mV)
Nitrogen	NO_{3^-}	Nitrate	N_2O, N_2, NH_4		220
Manganese	Mn^{4+}	Manganic	Mn^{2+}	Manganous	200
Iron	Fe^{3+}	Ferric	Fe^{2+}	Ferrous	120
Sulfur	SO_4^{2-}	Sulfate	S^{2-}	Sulfide	-75 to -150
Carbon	CO_2	Carbon dioxide	CH_4	Methane	-250 to -350

et al. (1985) found that in an undisturbed watershed of the Sierra Nevada over 99% of the incoming nitrate-nitrogen was converted to nitrous oxide (N_2O) or elemental nitrogen (N_2)

Reduction of manganese from manganic (Mn^{4+}) to manganous (Mn^{2+}) form occurs at a redox potential of approximately 200 mV (Gambrell and Patrick 1978). Reduced Mn is mobile in the soil profile and can be toxic to plants at high concentrations (Armstrong 1982). When redox decreases to around 120 mV, ferric iron (Fe^{3+}) is reduced to ferrous iron (Fe^{2+}) (Gambrell and Patrick 1978). The reduction of Fe^{3+} to Fe^{2+} is most discernable since the brownish-red color of Fe^{3+} hydroxides change to the grey or bluish-grey of Fe^{2+} hydroxides. In soils that are seasonally waterlogged, a mottled pattern of Fe^{3+} and Fe^{2+} is apparent. A soil horizon with this mottled pattern or solid bluish-grey matrix is referred to as a gleyed horizon (Buol et al. 1980). The red iron deposits often seen at the outflows of springs or seeps are an indication of reducing conditions in the soil profile behind the spring. Reduced iron (ferrous) is water soluble and can move with ground water until it reaches an aerobic environment where it is oxidized to ferric iron and precipitates out of solution.

Sulfur compounds are the next electron acceptors after iron as redox potential decreases. Sulfates are reduced to sulfides at a redox potential of about -150 mV (Gambrell and Patrick 1978). This is typified by a "rotten egg" smell characteristic of some marshes and riparian communities. Conversion of carbon dioxide (CO_2) or methyl groups to methane occurs when CO_2 and methyl groups are used as electron acceptors by certain bacteria. This requires a low redox potential (-250 to 350 mV) and the absence of all other terminal acceptors (Mitsch and Gosselink 1986). This appears to be the final redox system in soils (Ponnamperuma et al. 1966). Ferrous, manganous and sulfide ions can be toxic to plants at high concentrations (Armstrong 1982). However, low levels of these nutrients reduce the competitive ability of plant species that are not adapted for growth in soils of low redox potential. This is reflected in the distribution of plant communities over landscapes influenced by shallow water tables. For example, Pierce (1953) found in Wisconsin, sedge *Carex* spp. communities occupied sites of lower redox potential (-318 mV) than cattail *Typha* spp. communities (-216mV). In the same study aspen *Populus tremuloides* communities occupied sites of higher redox potential (-107mV) than black spruce *Picea mariana* communities (-262mV).

Under lentic situations, redox potential decreases with increasing depth from the soil surface (Gambrell and Patrick 1978; Howes et al. 1981; DeLaune et al. 1983; Bertness and Ellison 1987). However, we have found different situations in riparian zones. In a *Carex-Poa pratensis*-mixed forb riparian community along Catherine Creek, the redox potential did not uniformly decrease with increasing depth (Table 2). The redox potential data (Table 2) were collected 6 July 1988. At this sampling date, water table depth was 35 cm. Reduced conditions existed at the 5-and 10-cm depth (112 and -116 mV, respectively). However, below the water table redox potential increased to 374 mV. The higher redox potentials found in the lowermost sampling depth may be a function of subsurface flow of oxygenated water.

Ecological inferences on vegetation-environmental dynamics can be made from comparisons of these data (Tables 1 and 2). At all of our sampled depths, reduced forms of nitrogen, manganese, and iron were present. Redox readings at the 5- to 10-cm depth indicated that Fe^{3+} was reduced to Fe^{2+}. This site is restricted to those plant species that have adaptations to facilitate survival in an environment where reduced iron is present. Anthropogenic activities that change water relations of this community could alter redox potential and ultimately change vegetation composition.

Table 2.—Mean (SE) soil redox potential in a *Carex-Poa pratensis*-mixed forb community along Catherine Creek, Oregon, 6 July 1988.

Depth (cm)	Redox potential (mV)
5	112 (25)
10	-116 (18)
30	386 (32)
60	374 (7)

The effects of human-induced disturbance on redox potential, pH, organic matter decomposition, and therefore, the rates of nutrient cycling are only beginning to be investigated in riparian ecosystems. Redox potential and subsequent effects on soil chemistry strongly influence the patterning of vegetation communities. Many riparian species are intimately adapted to survive periods of low soil redox potential. These adaptations may include aerenchyma, thickened cuticles, and oxygen loss at the root tip (radial oxygen loss) (Armstrong 1972, 1982). Different types riparian plant communities will display differences in redox potential. For example, we sampled redox composition along a gradient of decreasing soil saturation during the period of vegetation anthesis (July 1988). Redox potential at the 10-cm depth was -164 mV for emergent, tall mannagrass *Glyceria grandis* stands, -48 mV in wet meadow beaked sedge-dominated *Carex rostrata* stands, -165 mV in Nebraska sedge dominated stand *Carex nebraskensis*, and 570 mV in Kentucky bluegrass *Poa pratensis*-timothy *Phleum pratense* communities. Tall mannagrass appears to be well adapted for survival in a highly reduced environment having aerenchyma and hollow stems which probably allow for greater oxygen diffusion to the roots. Radial oxygen loss creates aerobic conditions in the environment immediately surrounding the plant roots (Teal and Kanwischer 1966; Armstrong 1970). This would result in oxidation of the reduced forms of iron, manganese, and organic soil toxins before they diffuse to plant tissues. Evidence of this can be seen through observation of a thin reddish coating (oxidized iron) on the root surface of many wetland species with roots in waterlogged soils.

Beaked sedge and Nebraska sedge appear to be adapted to lower redox potentials and have a thickened epidermis and, in the case of Nebraska sedge, a glaucous coating on the leaf blades. These are adaptations that decrease transpirational water loss by plants and, hence, decrease uptake of reduced soil toxins in the soil water. Kentucky bluegrass and timothy are found at the drier end of the gradient and do not appear to have any adaptations for growing in soils with lower redox potentials (waterlogged) for extended periods during the growing season. In summary, the distinctive patterning of vegetation communities in riparian zones is only one indication of ecosystem diversity. Each vegetation pattern indicates a unique combination of biogeochemical conditions which in turn influence the rhizosphere, vegetation, terrestrial wildlife communities, and the aquatic system.

Seasonal Fluxes in Redox Potential

Given differences in water table depth, redox potential, and vegetation composition, it is clear that biogeochemical cycles are unique and complex along the spatial gradient from emergent vegetation stands to dry meadows. Just as there are spatial gradients of redox potential, so are there temporal gradients of redox potential within any given plant community. In northeastern Oregon, we have found that redox potential is low at the onset of the growing season when soils are saturated (Table 3). Gradually, redox potential increased as the soil temperatures increased and soil moisture decreased. A depression in redox potential at the 10-cm depth occurred on both May 23 and June 6 sampling dates. This was due to heavy spring rains that resaturated the soil horizon.

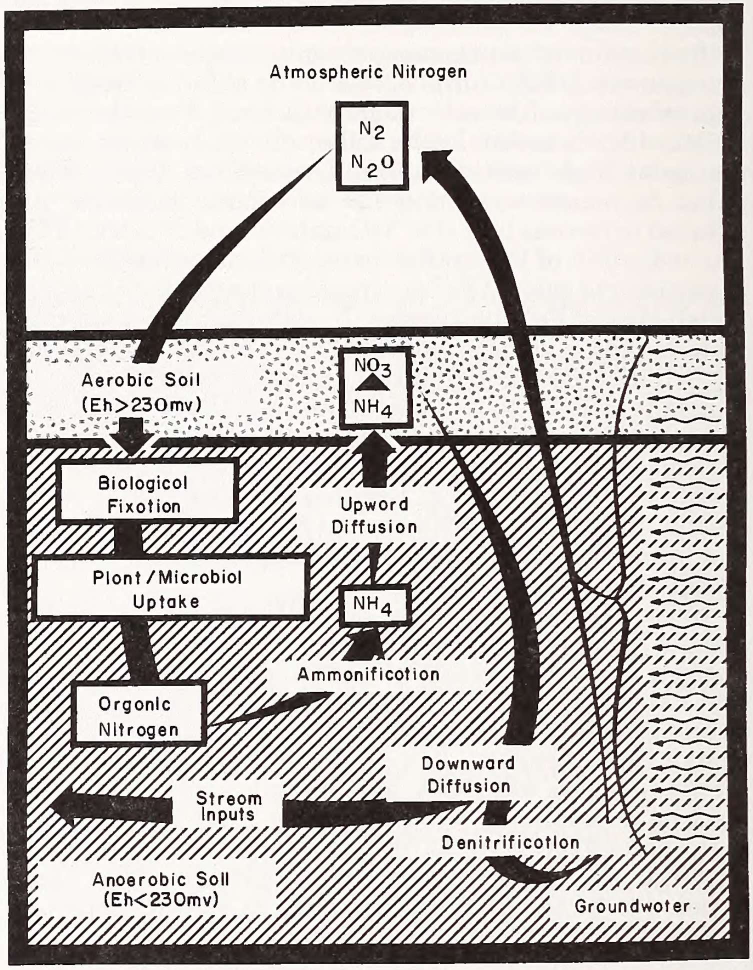
Redox values at the onset of the growing season are well within the range for conversion of oxidized iron to reduced iron. Throughout the sampling period, reduced forms of manganese and iron would be expected to be present in the soil profile (Table 3). Redox potential indicates that denitrification processes are occurring well into early June.

This is a very stressful ecosystem in that plants survive in an ecosystem characterized by dramatic seasonal changes. Plants must begin growth in a highly reduced environment and cope with high, potentially toxic, concentrations of reduced elements in an anaerobic environment as well as cold soil temperatures. By the end of the growing season, soil environments are quite different. Soils are dry, well oxidized, and may be quite warm.

Nitrogen in Riparian Areas

Despite the fact that riparian zones differ from other wetlands by the presence of running water, it is likely that nitrogen cycling pathways described for wetlands are similar in the riparian zones of northeastern Oregon (Figure 1). Nitrogen has been found to be a limiting nutrient to vegetation productivity in salt marshes (Valiela and Teal 1974), freshwater tidal marshes (Simpson et al. 1978), and freshwater marshes (Klopatek 1978; Grace 1988). Degrees of nitrogen limitation have not been quantified in riparian zones of the intermountain western USA.

Figure 1.—Nitrogen cycling pathways in undisturbed riparian zones of northeastern Oregon, as indicated by redox potential (Eh).



Biological fixation of atmospheric nitrogen (N_2) is only known to occur within a small group of free living blue-green algae, and bacteria, symbiotic bacteria, and actinomycetes (Sprent 1987). Nitrogen fixation has been quantified in salt marshes (Kaplan et al. 1979) and in freshwater lakes (Viner and Horne 1971). However, Golterman and Kouwe (1980) feel it is unlikely that nitrogen fixation contributes significantly to the nitrogen cycle of freshwater lakes. Ammonium-nitrogen (NH_4-N), the product of nitrogen fixation, is immobilized into a variety of compounds in the biomass of nitrogen fixers or their hosts. Upon organic matter decomposition, nitrogen is released in this form. Under anaerobic conditions ammonium may become locally abundant and plants can take up nitrogen in this form (Bidwell 1979; Mitsch and Gosselink 1986). When anaerobic soil layers are present, ammonium can diffuse into an aerobic horizon where it is rapidly converted to nitrate-nitrogen (NO_3-N) by the bacterially mediated proc-

Table 3.—Mean (SE) redox potential and soil temperatures at two depths and water table depths during spring and summer in a *Carex-Poa pratensis*-mixed forb community along Catherine Creek, Oregon, 1988.

Date	Redox potential (mV) depth (cm) 5	Redox potential (mV) depth (cm) 10	Temperature °C depth (cm) 5	Temperature °C depth (cm) 10	Watertable depth (cm)
April 14	-40 (9)	-24 (49)	10.4	10.4	11
April 28	-1 (32)	-30 (27)	10.5	10.2	11
May 12	114 (15)	118 (27)	12.6	11.2	12
May 23	218 (9)	-167 (8)	13.3	12.4	8
June 6	7 (48)	-119 (8)	11.7	11.2	8
June 20	311 (22)	295 (1)	15.4	14.7	21
July 6	374 (8)	386 (32)	13.6	12.7	35

ess of nitrification. Nitrate-nitrogen is very labile, and because of its negative charge, is mobile in the soil profile (Hausenbuiller 1978); the majority of nitrogen entering the riparian zone via ground water is in this form (Jacobs and Gilliam 1985).

If nitrate-nitrogen is not immobilized by organisms, it can be leached into groundwater or denitrified in anaerobic layers (Patrick and DeLaune 1972; Ponnamperuma 1972; Gambrell and Patrick 1978). In riparian zones, nitrate-nitrogen present in subsurface flows can be denitrified in those areas of the soil profile where redox potential is less than 230 mV (Table 1). Nitrate-nitrogen entering these anaerobic areas is converted into the gaseous forms of N, nitrous oxide (N_2O) or dinitrogen (N_2), the relative proportions of which are dependent on pH (Van Cleemput 1975). Nitrate-nitrogen that is not denitrified or biologically incorporated will be discharged to the stream.

Nitrate-nitrogen can greatly influence the water quality of streams and lakes where it is a limiting nutrient. Increased loading of nitrate-nitrogen in lakes or streams can cause algal blooms (Harned 1982). When algae that have accumulated during a bloom die and decay, the decomposition processes greatly depresses levels of dissolved oxygen in the water resulting in death of aerobic organisms or changes in species composition (Ewel 1976). Algal growth caused by elevated nitrate levels will also decrease the clarity in lakes and rivers thereby decreasing aesthetic value (Coats et al. 1976). Nitrate-nitrogen can also be toxic to humans; for example the World Health Organization recommends less than 11.3 mg N/L in drinking water.

Recent research has shown that riparian zones are important sites for denitrification. Rhodes et al. (1985) found that in an undisturbed watershed of the Sierra Nevada, California, over 99% of the incoming nitrate-nitrogen was denitrified. Vegetation uptake of nitrate-nitrogen was found to be insignificant in their study. In North Carolina, Jacobs and Gilliam (1985) found that 10 to 55 kg/hectare/yr of nitrate-nitrogen was denitrified in the riparian zone of streams bordering agricultural fields. Gambrel et al. (1975) and Gilliam et al. (1978) found significant losses of NO_3-N in the riparian zone of North Carolina streams. In Georgia, Lowrance et al. (1984) found nitrate-nitrogen concentration in subsurface water leaving agricultural fields decreased 66% as it passed through the riparian zone. It was concluded that the riparian forest also acts as a sink for calcium, magnesium, potassium sulfate, and phosphorus.

Phosphorus Riparian Areas

In numerous wetland ecosystems, phosphorus has been found to be a limiting nutrient. It was reported to be limiting in northern bogs (Heilman 1968), southern deepwater swamps (Mitsch et al. 1979), and freshwater marshes (Klopatek 1978). Phosphorus was not considered to be a limiting factor in areas of rice cultivation (Patrick and Mahapatra 1968; Gambrell and Patrick 1978), and salt marshes (Whitney et al. 1981; Grace 1988). Riparian areas have been reported to act as a sink for phosphorus (Cooper and Gilliam 1987), but no criteria has been established to ascertain whether phosphorus is a limiting nutrient in riparian zones.

Although not used in microbial respiration processes as is iron, manganese, or sulfur, phosphorus is affected by soil redox potential. Availability of phosphorus increases in anaerobic soil compared to aerobic (well drained) soils (Shaprio 1958; Khalid et al. 1976). Patrick and Wyatt (1964) found that extractable phosphorus increased by a factor of three as redox potential was reduced from 200 to -200 mV. DeLaune et al. (1981) determined that the concentration of dissolved phosphorus was highest under low redox (-200 mV) and low pH (5.0). Ponnamperuma (1972) attributed the increase of soluble phosphorus to three factors: (1) hydrolysis of ferric and aluminum phosphates, (2) release of phosphorus adsorbed to clays and hydrous compounds by anion exchange processes, and (3) reduction of ferric iron compounds containing phosphorus to more soluble ferrous compounds. High levels of phosphorus can cause algal blooms with the same results as elevated nitrate concentrations discussed previously.

Riparian zones principally influence phosphorus concentration through their function as sites of deposition for phosphorus enriched clay particles or by absorption of phosphorus from overlying water by soil or sediments. Stream banks and sediments have been reported to absorb significant quantities of phosphorus (Brinson 1977; McCallister and Logan 1978; Yarbro 1979). Cooper and Gilliam (1987) found deposition of sediments to be more important than sediment absorption as a mechanism of phosphorus removal from streams in North Carolina. Phosphorus is also immobilized in the riparian zone by vegetation uptake. Yarbro (1979) estimated that annual growth increment of trees accounted for 0.6 to 1.2 kg phosphorus/hectare in a North Carolina floodplain forest.

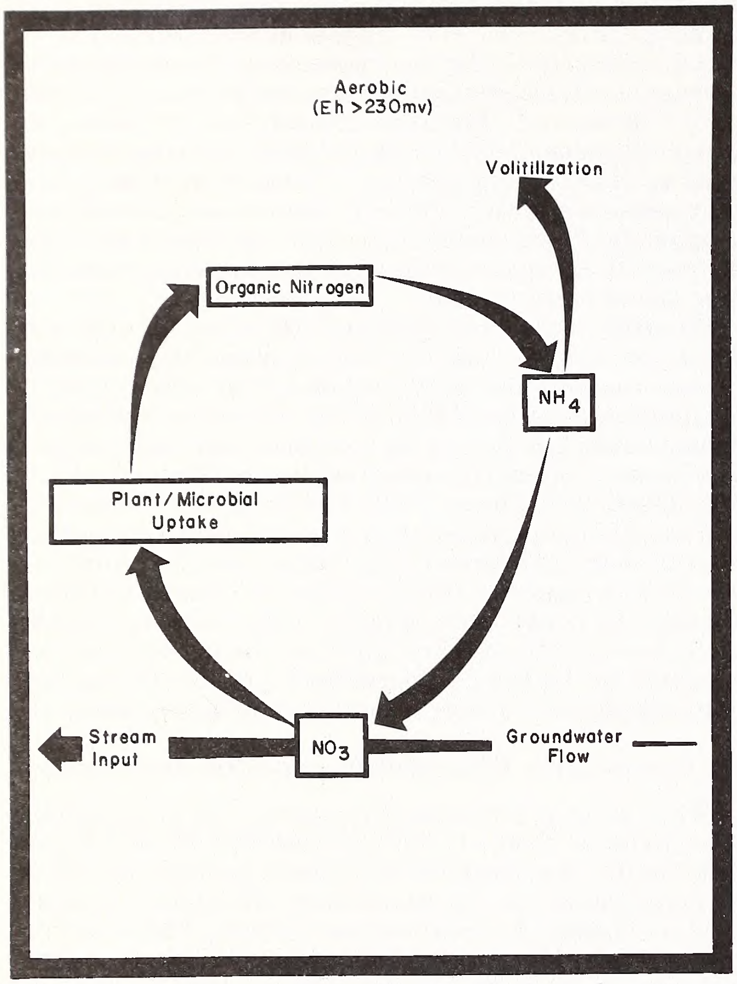
Anthropogenic Effects on Biogeochemical Cycles

When redox potential is lower than 230 mV, denitrification will occur (Table 1). This process may be very important for the maintenance of aquatic ecosystems. When nitrate-nitrogen occurs at abnormally high concentrations, a reduction in stream water quality will take place as a result of algal blooms, turbidity, and, ultimately, oxygen depletion (Harned 1982). Because it is negatively charged, nitrate-nitrogen ions are very labile in soils and ground water (Hausenbuiller 1978).

Many undisturbed, montane, low gradient riparian areas of the western USA are characterized by high water tables throughout most or all of the year. In wet meadows, the anaerobic layers will be close to the soil surface throughout the year. In the meadows of Catherine Creek, we have found that organic matter contents are usually highest at the soil surface and decrease with soil depth. Therefore, optimal environments for denitrifying microorganisms exist and include a rich supply of organic matter as a source of energy and anaerobic conditions for much of the growing season. Hussey et al. (1985) found that significant numbers of denitrifying bacteria existed in the upper 5 to 15 cm of riparian soils. Rates of denitrification were lower at the 30-cm depth than at 5 cm. Soils close to the edge of the stream contained more organic matter, moisture, and higher rates of denitrification than other sites.

Conditions allowing for high rates of denitrification will disappear when riparian zones are destroyed as a result of erosional downcutting of the stream channel (Figure 2). Erosional downcutting increases the soil depth at which anaerobic conditions occur. It is probable that organic matter available for use as an energy source will be less at these deeper depths. Additionally, as the riparian zone decreases through channelization, drainage, removal of beaver dams, or downcutting, the total area in which denitrification can occur decreases. Hydraulic residence times would also be decreased. Hydraulic residence time in

Figure 2.—Nitrogen cycling pathways in degraded riparian zones of northeastern Oregon, as indicated by redox potential (Eh).



riparian ecosystems is that period in which ground water is present in the riparian zone as it moves from uplands to the stream channel. We hypothesize that decreasing hydraulic residence times through channelization or erosional downcutting, as a result of poor management practices, reduces the potential for biological interaction (i.e., nutrient uptake and chemical transformation) between riparian vegetation, microorganisms, and ground water. Alteration in both channelized and overgrazed riparian systems can be characterized as changes from an equilibrium of lateral inputs and outputs to an unidirectional movement and leaching into the aquatic system (Brinson et al. 1981). For example, channelized coastal streams in North Carolina were found to have higher concentrations of nitrate-nitrogen than in unchannelized streams (Kuenzler et al. 1977). The source sink relationship of nitrate-nitrogen in an intact riparian zone can be overridden during storm events when increased subsurface flows from precipitation decrease hydraulic residence time in the riparian zone (Coats et al. 1976; Melgin 1985).

Numerous examples exist in central Oregon and other regions of the semi-arid western USA where stream flow originating from intact riparian zones is perennial, but an abused or degraded section of the same stream is ephemeral (Elmore and Beschta 1987). This reflects a decrease in hydraulic residence time in the degraded section that results in decreases in total riparian area, lower rates of biological interaction with surface flows, lower quantities of nutrient uptake by vegetation, lower quantities of nutrients stored in the riparian ecosystem, and greater quantities exported out of the watershed.

The decline in surface biomass of vegetation in degraded riparian zones or exclusion of the stream from its riparian zone by channelization or erosional downcutting will result in reduced amounts of sediment trapping in the riparian zone. Many nutrients are also deposited in the riparian zone during high flows and are lost to downstream systems in degraded situations. Yarbro (1979) found that sediments in the riparian zone of a North Carolina stream trapped 1.7 kg/hectare of phosphorus. Cooper and Gilliam (1987) found that 50% of the phosphorus leaving upland agricultural fields in North Carolina passed by the riparian zone they studied.

Conclusion

The condition of the riparian zone is a reflection of many complex and biogeochemical processes with linkages to both aquatic and terrestrial communities. Biogeochemical processes greatly influence water quality, the aquatic ecosystem, and the pattern and productivity of the riparian vegetation. In our study, preliminary data show that Kentucky bluegrass-timothy communities which are not adapted to anaerobic conditions occupied areas of higher redox potential than tall mannagrass communities which are adapted to anaerobic conditions. Currently, little quantitative data exist on the effects of grazing, logging, channelization, recreation, or other anthropogenic activities on biogeochemical cycles in western riparian ecosystems. We do know that isolating the stream from its riparian zone, either by channel downcutting or by channelization, seriously impairs the functional integrity of the riparian zone. Source-sink relationships between riparian and stream ecosystems are severed. This ultimately will result in declines in those resource values associated with water quality, livestock grazing, fisheries, and wildlife diversity and productivity. Research should focus on quantifying the landscape-level relationships between the terrestrial, riparian, and aquatic ecosystems.

Developing land management systems that allow ecosystem processes to function as close to a natural equilibrium as possible will insure a stable output of resource values for all interested users. Without an increased understanding of how riparian ecosystems function and the development of management strategies that reflect this knowledge, we can expect further declines in the quality and productivity of our riparian ecosystems.

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Management of Winter Soil Temperatures to Control Streambank Erosion

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Abstract.—Winter soil temperatures were measured in streambanks under different vegetation cover conditions in northeastern Nevada. Grass provided significant streambank insulation at two different elevations and aspects when compared to bare soils. Grass cover moderated average maximum and minimum soil temperatures, reduced average daily soil temperature fluctuations, and decreased the number of days that the soil temperature fell below 0° C. Previous research on horizontal soil surfaces has shown that frost-heaving and freeze-thaw cycles alter soil strength. Therefore, it is postulated that the formation of soil ice weakens the internal structure of streambanks. Weakened banks are less able to resist disturbance from high velocity run-off flows and ice floes and overburden pressure exerted on the weight-bearing strata. The temperature modifications resulting from vegetative cover appear to be sufficient to reduce the number of freeze-thaw cycles along the streambank face. Riparian management should be designed to provide sufficient vegetative cover over the winter to insulate streambanks and maintain soil strength.

Streambank stability is determined internally by the soil's ability to resist displacement and externally by vegetative cover and streamflow characteristics. Some of the external forces which work to displace streambank soils are tractive force from high velocity flows and ice floes, gravity, and trampling. A streambank's ability to resist these forces (i.e., soil strength) can be internally weakened by ice formation in the soil and frost-heaving. By understanding the processes which weaken streambanks, land managers can develop streamside management strategies which reduce streambank vulnerability and favor functional stability.

As soil water freezes and expands, it increases soil volume by pushing soil particles above the level of the original soil surface. This effect is commonly observed in the formation of needle ice which pedestals soil particles. Severe frost formation can lift large amounts of soil and objects as large as fenceposts. When soil displacement occurs on a nearly vertical surface, such as the face of a streambank, gravity transports the particles locally and streamflow can carry them off-site. Susceptibility to frost formation and magnitude of soil weakening from freezing and thawing may vary with soil texture, bank height, and arrangement of soil layers. The frequency and depth of freezing, however, reflect the extent to which the soil is exposed directly to air temperatures. Insulation appears to be one mechanism by which streambank vegetation helps stabilize and form bank shape. This paper presents data that support the hypothesis that streambank vegetation has powerful insulation potential. The paper also reviews literature that suggests insulation of streambank soils may be important to overall bank stability, and addresses the implications and direction for management which derive from this information.

Literature Review

Ice formation in the horizontal soil surface and the resultant heaving and erosion have long been recognized by agriculturists, silviculturists, and engineers as important mechanisms of soil aggregate destruction. For ice to form in soil, subfreezing temperatures, water, and, usually, small soil pore spaces must be present. The magnitude of soil ice formation varies with soil type, moisture content, and temperature gradient (Hinman and Bisal 1968; Penner 1968; Chamberlain 1981; Meentemeyer and Zippin 1981). Frost-heaving may be more prevalent in soils with higher bulk densities, probably because smaller soil pores facilitate the capillary flow of water to the freezing zone and are quickly filled by the expanding ice crystals (Heidmann and Thorud 1975; Chamberlain and Gow 1979). However, leaf litter and snow insulation appear to be more important factors in determining frost susceptibility than soil type (Thorud and Anderson 1969).

Ice formation apparently creates a suction (from a moisture gradient, or negative matric potential) in the immediate soils which draws water from underlying layers (Domby and Kohnke 1955; Broms and Yao 1964; Soons and Greenland 1970; Pikul and Allmaras 1985). Soil structure is increasingly altered as moisture content increases in well-aggregated soils (Logsdail and Webber 1959; Benoit 1973; Bullock et al. 1988). Saturated soil conditions during thawing lower the soil's internal angle of friction, particularly in soils that were frozen slowly (1.27 cm/d) or subjected repeatedly to freeze-thaw cycles (Broms and Yao 1964). The net result is decreased slope stability. Slope destabilization also results from a decrease in shearing strength and bearing capacity when soil density decreases from frost-heaving (Broms and Yao 1964; Formanek 1983). Ice expansion that compress rather than heavees soils can also leave cracks (Chamberlain and Gow 1979). Increased moisture, decreased density, and cracks weaken soil strength.

Study Site

Gance Creek is primarily a snowmelt-fed stream in the North Fork of the Humboldt River basin in northeastern Nevada. The stream originates in the Independence Mountains, about 64 km north of Elko, Nevada, where streamflow is perennial and supplemented by numerous small springs. Precipitation in this area averages about 63.5 cm annually, falling primarily as snow (unpublished data, Saval Research Project, U. S. Bureau of Land Management). However, the 1986-1987 winter was particularly dry and the study site experienced substantially less snowpack than normal. After leaving the mountains, Gance Creek flows across a typical northern Great Basin big sagebrush *Artemisia tridentata wyomingensis,* rabbit brush *Chrysothamnus viscidiflorus*, and bluebunch wheatgrass *Agropyron spicatum* valley. Irrigation water withdrawal occurs in some years and the lower reaches often dry up for part of the summer. Precipitation in this area is about 33 cm annually, falling primarily as snow. The snowpack was also low in 1986-1987, but it did blanket the area. Although vegetation and soils can have very patchy arrangements in riparian areas, the specific location of the temperature measurements were in sandy loam soils with Kentucky bluegrass *Poa pratensis* and willow *Salix* spp. cover in the upper reaches and also in the valley.

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Methods

Stainless steel-fiberglass wafer temperature sensors were buried about 3 cm into the face of streambanks in pairs of exposed and grass-covered (with Kentucky bluegrass) soils. Because the calibration of stainless steel wafer sensors can vary among wafers, several sensors were tested in the laboratory and those with similar responses were selected for field use. Data recorders logged average temperature every 3 h from January through May 1987. Two pairs of sensors were buried at the upper elevation site and two pairs at the lower elevation for a total of four sets of paired sensors. The upper elevation site was at 2,048 m, where the snow free period extended from 2 April to 13 May 1987. One sensor of each pair was under a 1- to 2-cm deep cover of grass and litter. The other sensor of each pair was in exposed streambank soil. One pair faced west and the other faced east. The lower elevation site, at 1,786 m, was snowfree from 6 March to 6 May 1987. Although the ground cover was the same as the upper elevation site (1-2 cm of litter and Kentucky bluegrass), there was also a sparse overstory of willow over the west-facing pair. The lower site had one west-facing pair and one east-facing pair.

The temperature data were divided into periods of snow cover and no snow cover (< 3 cm depth); only data from the no-snow period were used to avoid confounding the results with insulation effects from snow. Average daily soil maximum temperature, minimum temperature, and temperature change (maximum minus minimum) were determined for each sensor point. Paired *t*-test analysis compared the effects of grass cover and bare soil on the three temperature variables only in streambanks with no snow cover.

Results

Because snow is an effective insulator, the analysis of grass cover versus bare soil was performed on soil temperatures without snow cover. The daily temperatures crossed 0° C almost twice as often in bare soils than in grass-covered soils (Table 1). This is used as an indication of the relative number of freeze-thaw cycles. Further analysis showed that grass-covered soils had significantly lower average maximum temperatures and significantly higher minimum temperatures, resulting in smaller average daily temperature fluctuations than in uncovered soil (Table 2). Each site was examined and photographed every week or 2 weeks throughout the data collection period; concrete ice and needle ice formation in the exposed banks were observed. Loose soil on snow covering the toe of the stream bank was also noted beneath exposed banks.

Table 1.—Percent of days with streambank soil temperature change crossing the freezing point along Gance Creek, spring 1987. Soils were snow-free.

Station	Grass cover	Bare soil
Pair 1, lower	48%	90%
Pair 2, lower	47%	88%
Pair 3, upper	39%	65%
Pair 4, upper	52%	71%

Table 2.— Paired *t*-test comparing streambank soil temperatures at stations on Gance Creek with grass cover or bare soil in spring 1987. Soils were snow-free. Asterisks denote significantly higher mean temperature ($P < 0.05$* or $P < 0.01$**). Degrees of freedom=3.

	Average maximum temperature (°C)	Average minimum temperature (°C)	Average daily temperature change (°C)
Air	12.5	-3.4	15.90
Grass soils	12.1	0.45	11.65
Bare soils	18.5	-2.98	21.49
t value comparing grass and bare soils	3.568 *	10.46 **	4.742 *

Discussion

Temperature Effects on Soils

In bare soils without snow cover, wide daily temperature fluctuations occurred. Grass cover significantly moderated the daily fluctuations in soil temperatures and greatly reduced the number of days that the soil temperatures crossed zero, suggesting fewer freeze-thaw cycles and less opportunity for frost-heaving in grass-covered soil. Repeated freeze-thaw cycles can magnify the effects of a single cycle. Formanek (1983) reported that the rate of water migration to the freezing front in saturated soils increased with each freeze, up to three freezes. Broms and Yao (1964) found that one cycle of rapid freezing (7.6 cm/day) reduced the strength to 50-70% of that found in control soils, and repeated freeze-thaw cycling further reduced the strength to 10-20% of the controls.

Colder temperatures also increase the effects of freezing. Changjian and Zongyan (1981) investigated horizontal frost heave thrust acting on buttress construction and reported that the thrust of the soil increases as the temperature falls, until it reaches a maximum value of about -7° C. Thus, colder temperatures increase the likelihood of soil displacement and streambank damage. Weakening the internal structure of a streambank with repeated freeze-thaw cycles leaves the bank vulnerable to accelerated failure due to gravity, streamflow, ice floes, and animal trampling.

Vegetation Effects on Temperature

The grass cover on the streambanks moderated soil temperatures in much the same way plant cover and mulches do on horizontal soil surfaces. It is notable that significant temperature differences were found with so little vegetative cover; more cover could dramatically alter the temperature fluctuations. Vegetation lowers both surface wind velocity and the turbulent exchange of heat between the soil surface and the atmosphere, thus buffering temperatures at the soil surface. Furthermore, organic matter forms air pockets and roots loosen the soil, creating more air spaces which lower heat conductivity into and through the soil (Tyrtikov 1969). Atkinson and Bay (1940) reported that depth of frost in agricultural fields decreased as the depth of vegetal cover or snow cover increased. Straw mulch on plowed and disked fields produced average daily soil temperatures similar to soils in mulched and bare silt-loam fields (Kohnke and Werkhoven 1963); however, daily soil temperature fluctuations in the bare fields were two times greater than in the mulched fields, and the frequency of freeze-thaw cycles was 3.6 times greater in the bare fields. Although frost did not form in soil under a standing stubble surface cover, the maximum soil frost penetration in bare surface plots was 1.3 cm (Pikul and Allmaras 1985). Thorud and Anderson (1969) found that layers of leaf litter or snow increased the freezing time to selected depths, decreased the overall depth of the freeze, and pine needles insulated better than oak leaves. Wet litter was not as effective as air-dry litter, but a layering of litter and snow seemed to have an additive effect. Tyrtikov (1969) also reported more moderate maximum and minimum temperatures and less severe freezing in soil under coarse pasture (need grass *Calamagrostis langsdorffi* and thistle *Cirsium heterophyllum*) than from bare ground, even when both the pasture and bare soil had a snow cover. Decker and Ronningen (1957) found considerably more frost-heaving in bare plots than under smooth bromegrass *Bromus inermis*, Ladino clover *Trifolium repens*, orchardgrass *Dactylis glomerata*, alfalfa *Medicago sativa* or Kentucky bluegrass sod. The least disturbance occurred under Kentucky bluegrass, while the Ladino clover, with its small shallow root system and sparse vegetative cover, was the most susceptible to soil frost disturbance. In orchardgrass, heaving occurred between the grass clumps but seldom next to or within clumps.

Management Implications

Management promoting good streambank insulation can help control the frost-heaving and internal soil weakening and perhaps reduce bank failures. For example, along stream reaches where grass is the predominant streambank cover, early light grazing and then rest to allow plant regrowth before winter, leaves an insulating layer of vegetation. In shrub communities, where snow canopy on the branches and litter provides insulation, management can be designed to encourage dense woody growth. Some areas may have to be grazed early when an abundance of other palatable vegetation can reduce the pressure on the less palatable willow (W. Platts, U. S. Forest Service, personal communication). Although not tested in this study, some types of vegetation may insulate better than others, such as occurs with crops on agricultural fields. Vegetative insulation on top of the bank may also be important in preventing frost in the soil surface which may lead to stress cracks and slab failures. Managing vegetation to provide natural insulation is one way to influence channel stability in some climates.

Acknowledgments

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Characteristics of Riparian Plant Communities and Streambanks with Respect To Grazing in Northeastern Utah

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Abstract.—Streambanks and associated riparian vegetation were studied in grazed and ungrazed pastures along Big Creek, Rich County, Utah, to determine whether differences in streamside community type composition and condition were related to differences in streambank morphology. Considerable structural difference was observed between grazed sites and sites where grazing has been suspended or greatly reduced for nearly two decades. In the ungrazed sites, structures that had been installed to improve fish habitat had apparently raised water tables and thus were associated with changes in riparian vegetation. Similar trends seem to be starting in unimproved sites that have been protected from grazing for only 4 years. Streambank morphology varied widely among the various community types. Certain riparian community types (e.g., those characterized by *Carex* spp.) were able to maintain bank structure under grazing use, but others (e.g., those characterized by *Poa pratensis*) appeared to be highly unstable when grazed. Higher order classification revealed groups of streamside community types that, in the absence of grazing, could be expected to confer similar streambank characteristics. An apparently distinct, successional sequence from sandbar-dominated communities through *Juncus balticus*-dominated communities to *Poa pratensis*-dominated communities or sedge-dominated communities was evident. Where sedges can become dominant, they clearly create the most optimal streambank structure. Even under grazed conditions, some of the optimum bank characteristics were associated with this community type. Moderate grazing pressure after viable sedge communities have become reestablished may be acceptable, but the managers responsible must ensure that CAREX community types do not revert to less favorable communities like POPR.

Dispersed throughout the vast rangelands of western North America are numerous ephemeral, intermittent, and perennial streams and wetlands. While of small areas themselves, these streams and wetlands constitute habitats where water is less of a limiting resource than on the surrounding uplands; wet islands in an arid sea, where plants requiring free or unbound water flourish. The mesic to hydric vegetation associated with these streams and wetlands defines a narrow riparian ecosystem, often referred to as a "corridor" when associated with streams, within the larger surrounding rangeland ecosystem. Such riparian ecosystems often support a higher diversity of terrestrial plant and animal species than the surrounding uplands and provide critical habitat components for diverse forms of aquatic life. They also attract livestock, which may congregate in riparian areas to take advantage of the relatively lush vegetation, readily available drinking water, soft soil, and shade; livestock may therefore spend a disproportionate amount of their time foraging within these fertile streamside corridors.

Growing recognition of these two important factors, that riparian areas provide critical resource values for fish and wildlife and that livestock are attracted to them and may use them more heavily than adjacent upland range areas, has led to increased study of riparian conditions and their relationship to grazing management. Several studies (Bryant 1982; Roath and Kruegar 1982; Platts and Nelson 1985b, 1985d) have shown the preference of cattle for riparian areas; others have focused on the differences in riparian physical (Crispin 1981; Platts et al. 1983b; Platts and Nelson 1985c) and biologic (Winegar 1977; Szaro and Pase 1983) conditions under a variety of cattle grazing strategies ranging from complete rest to season-long continuous grazing.

A serious shortcoming of early attempts to evaluate the relationship between grazing and riparian area conditions and to develop useful management guidelines was a lack of adequate integration of the physical and biological interactions occurring in riparian ecosystems. This shortcoming has been ameliorated somewhat by the application of habitat typing techniques, which were first developed for forest communities by Daubenmire (1952), to riparian plant communities. In contrast to the habitat type classification concept, which considers successional development of the observed stands and attempts to determine the potential climax type, the community typing concept as applied to riparian vegetation is restricted to existing species composition because succession in the riparian context is poorly understood (Youngblood et al. 1985).

Extensive riparian community type classifications have been developed for some Rocky Mountain areas (Tuhy and Jensen 1982; Youngblood et al. 1985) and are currently being developed in Great Basin watersheds in Utah (Platts and Nelson 1987) and Nevada. With these classifications, streambank and channel morphology and vegetal form of the various plant communities can be compared under different grazing treatments.

This report takes a first look at the vegetal composition and morphology of riparian plant communities and streambanks under grazed and ungrazed situations on Big Creek in Rich County, northeastern Utah. Fencing of a large portion of Big Creek in the late 1970s has led to extensive vegetal changes that can now be comprehensively examined. Fencing of another section of Big Creek in the early 1980s also permits evaluation of the rate at which these changes take place, providing insight into potential rehabilitative pathways[1] as riparian vegetation is released from grazing. As we expand such knowledge, a more thorough framework in which to develop grazing management strategies that promote realization of multiple-use values on western rangelands may develop.

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[1] Most riparian classifications devote a good deal of discussion to successional relationships of the types despite a stated lack of understanding of such sequences. Because of this lack of understanding, we have elected to use such terms as "progression" and "regression" in place of "succession" and "retrogression", respectively.

Study Areas

Two study areas were established in the Big Creek drainage west of Randolph, Utah. Big Creek is a perennial tributary of the Bear River on the eastern flank of the Bear River Range, a northward extension of Utah's Wasatch Mountains. Physiographically, Big Creek is within the Middle Rocky Mountain Province at the western edge of the Wyoming Basin (Fenneman 1931), but the Bear River drainage connects it with Great Salt Lake and the Great Basin (Basin and Range Province) opposite the Wasatch crest to the west.

Floristically, the unforested rangelands surrounding Big Creek are part of the Sagebrush-Wheatgrass Section of the Wyoming Basin Province (Bailey 1980). These uplands potentially comprise vast expanses of big sagebrush *Artemesia tridentata* accompanied by understory grasses, including bluebunch wheatgrass *Agropyron spicatum*. At the present time, the bunchgrass vegetation type represents only 9% of the upland range vegetation in the area and contains chiefly exotic crested wheatgrass *Agropyron cristatum*. Stands dominated by sagebrush and containing only about 5% grass comprise some 65% of the upland vegetation (USBLM 1979). Riparian vegetation, composed mainly of sedges *Carex* spp. and other graminoids, comprises less than 1% of the local vegetation but produces a disproportionately large amount of forage and thus has been an area of livestock concentration (USBLM 1979).

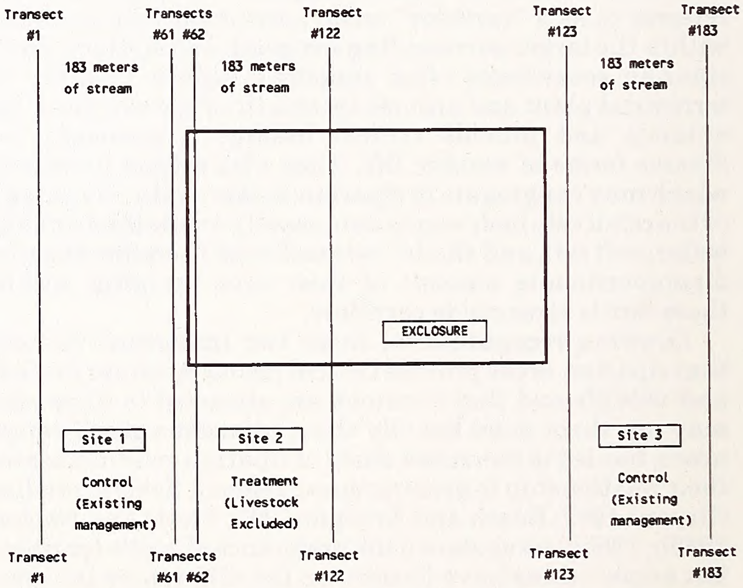
Water in Big Creek is moderately hard and bicarbonate buffered, with a mean annual flow of about 0.44 m^3/sec (D.A. Duff, U. S. Forest Service, personal communication). The stream supports populations of rainbow trout *Oncorhynchus mykiss*, cutthroat trout *O. clarki*, brown trout *Salmo trutta*, and Eastern brook trout *Salvelinus fontinalis*, as well as some non-game species, including mottled sculpin *Cottus bairdi* and suckers *Catastomus* spp. Aquatic habitat quality is generally poor for trout because the broad, shallow channel creates pools of low quality; fine sediments are abundant on the stream bottom, particularly in slow moving stretches; streambanks are poorly vegetated (Platts and Nelson 1985a, 1985c; Duff, personal communication); and stream canopy is sparse (Platts and Nelson 1985a). A livestock exclosure that released 0.8 km of Big Creek from regular annual grazing use was constructed in 1970, and about 40 instream repair[2] structures were installed in 1970 and 1971, both within and below the exclosure (USBLM 1979; Duff, personal communication). Despite occasional instances of unauthorized livestock entry, the exclosures have greatly improved riparian habitat conditions (USBLM 1979; Platts and Nelson 1985a, 1985c; Duff, Unpublished) and have led to channel and bank stabilization (Platts and Nelson 1985c; Platts et al. 1985). In 1983, construction was completed on a second livestock exclosure, somewhat larger than the first, approximately 2 stream-km upstream.

Livestock grazing on Big Creek has been largely for calf production. The grazing strategy of choice has been continuous (or season-long) grazing, with a season extending from mid-May to mid-September. A drift fence is located between the two exclosures to delay cattle from moving into the upper portion of the allotment, and a change to a deferred system[3] has been proposed (USBLM 1979) but has not been implemented. Livestock use of upland forage has been high, generally about 65% (USBLM 1979), but seems to have declined in the vicinity of the study areas since 1978 (Platts and Nelson 1983). Use of riparian vegetation has been much higher and has approached 90% where not protected (Platts and Nelson 1983, 1985a, 1985c).

Methods

Two study areas were established, one along 549 m of stream in conjunction with the first (downstream) exclosure (Lower Big Creek) (Figure 1) and one along 732 m of stream in conjunction with the newer (upstream) exclosure (Upper Big Creek) (Figure 2). Each study area was subdivided into treatment (rested) and control (grazed normally) sites of 183 m each. The lower study area comprised three sites: one control immediately below the exclosure, an adjacent treatment site immediately upstream and inside the exclosure, and one control about 0.6 km upstream and immediately above the exclosure. Treatments and controls had similar aquatic and riparian habitat conditions prior to construction of the exclosures (Platts and Nelson 1985a, 1985c). The upper study area comprised four study sites: a downstream pair of adjacent sites, with the control below the exclosure and the treatment site immediately above and within the exclosure, and an upstream pair, with the treatment site inside the fenced area and an adjacent control site outside and immediately above the exclosure.

Figure 1.—Schematic diagram of the Lower Big Creek study area.



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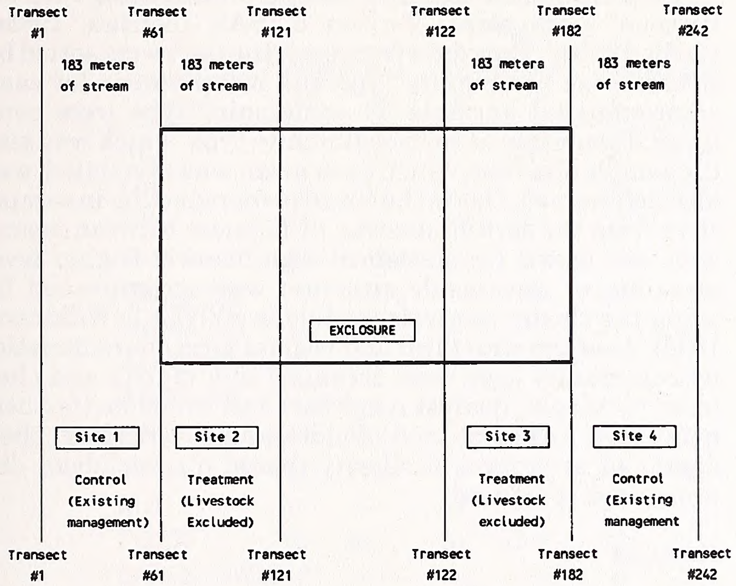
[2] Terms such as "repair structures" and "stream repair" have been used in place of the more commonly encountered terms, such as "habitat improvement structures" and "habitat enhancement" in order to distinguish attempts to rehabilitate degraded stream-riparian systems from simple attempts to enhance fishery productivity.

[3] A typical deferred grazing stategy is one in which the area to be grazed is divided into two pastures. Each season, one pasture is grazed early (i.e., for the first half of the grazing season), with use of the second pasture deferred until sometime near the middle of the grazing season, when the manager has decided that the vegetation will have become "ready". Range readiness often coincides with the time that particular range grasses ("key species") set seed ("seed ripe"). During successive grazing seasons, the pastures serve alternately for early and late use. The drift fence on Big Creek has typically been used merely to retard the entry of cattle into the upper portions of the allotment.

Figure 2.—Schematic diagram of the Upper Big Creek study area.



Riparian community type and streambank morphology data were collected using the transect method described in Platts et al. (1983b). Transects were established at 3-m intervals along the left streambank (downstream orientation) and perpendicular to the streamflow; thus, Lower Big Creek had 183 transects, and Upper Big Creek had 244 in pairs of 122 transects each. Riparian communities were classified (typed) along each transect line on each streambank, from the water's edge to at least 3 m back on the streambank. The length of each community type encountered along the transect was measured, but just those community types bordering the water's edge were considered in this report. Classification procedures are fully described in Platts and Nelson (1987) and were similar to techniques described elsewhere (Tuhy and Jensen 1982; Youngblood et al. 1985).

Classification of riparian vegetation is a new field of study and had not been attempted previously in the Big Creek area; pending more thorough investigation of riparian vegetation outside these study areas, the classification used for this study may ultimately be revised. Standard plant species acronyms used to name the community types, were based upon the dominant overstory and understory species. Where specific identification could not be accomplished, generic names or habitat descriptors were used (e.g., SALIX/DWM for a willow and downed woody material community type). Nonvegetated or sparsely vegetated areas were assigned names based on physical and biological characteristics. Consequently, and in contrast to the usual riparian community type classifications, we have referred to such community types as being mineral-dominated types in order to include the full range of ecosystem conditions. Precise descriptions of the individual community types that have been described for the Big Creek area can be found in Platts and Nelson (1987) and are described only briefly in this report.

Sixteen edge-of-water riparian community types were described (Platts and Nelson 1987) in the two Big Creek study areas (Table 1). Most community types occurred in both areas, but three (ROCK, HERB/SB, and RIBES/MH) were observed only in the lower study area and four (HERB/GB, AGST/SB, AGST/GB, and SALIX/MH) were found only in the upper study area. Although stream stage could conceivably influence what community type was present at water's edge, we consider this potential bias to be irrelevant for the purposes of this analysis because the average extent of the edge-of-water community types was 3.5 m.

Physical riparian habitat conditions were measured by using techniques described in Platts et al. (1983a, 1987). Variables evaluated included three morphological or structural variables (streambank angle, streambank undercut, and streamshore depth), three variables relating to vegetation form or condition (vegetation overhang, streambank stability, and forage production), and two vegetation variables that were directly related to livestock influence (vegetation use and streambank alteration). These measurements were sorted by community type and descriptive statistics (means, variances, and frequencies) were computed to evaluate relative characteristics of the individual community types. This reduced statistical reliability in many cases because of the attendant reduction in sample size, an effect that is considered, where necessary, in the following analysis. All structural variables were measured at as nearly the same time as practicable to minimize temporal variability.

Table 1.—Riparian community types described at water's edge along Big Creek, Utah (Platts and Nelson 1987).

Community type	Acronym
Mineral-dominated types[a]	
Sand bar	SB
Gravel bar	GB
Eroded bank	EB
Rock	ROCK
Herbaceous-mineral types	
Herbaceous sand bar	HERB/SB
Herbaceous gravel gar	HERB/GB
Agrostis stolonifera/sand bar	AGST/SB
Agrostis stolonifera/gravel bar	AGST/GB
Herbaceous types	
Mesic herbaceous	MH
Carex rostrata	CARO[b]
Carex nebraskensis	CANE[b]
Juncus balticus	JUBA
Poa pratensis	POPR
Riparian shrub-dominated types	
Ribes inerme/mesic herbaceous	RIIN/MH
Salix sp./mesic herbaceous	SALIX/MH
Salix sp./down woody material	SALIX/DWM
Upland shrub-dominated types	
Artemesia tridentata/*Poa pratensis*	ARTR/POPR
Artemesia tridentata/upland	ARTR/UP

[a] May contain some plant cover.

[b] CARO and CANE have been lumped into a combined CAREX community type for this study; however, some differences in occurrence are discussed where relevant.

Streambank Structure

Streambank angle is the angle formed between the streambank and the channel bottom.[4] The angle was measured directly from a clinometer that displays the degrees of arc of a surface. Angles of less than 90° are insloped and undercut, but those of more than 90° are outsloped and of little value in providing fish cover. Streambank undercut is the actual undercut of the bank along the transect line and measures the amount of overhanging bank cover available to fish. Undercut banks can be more stable than banks that are not undercut, because a large amount of plant root mass is required to hold the surface soil together while allowing subsurface soil to erode away beneath it to form the undercut. Streamshore water depth is the depth of the stream at the point where the streambank and water column meet. This depth is also a form of fish cover because it is associated principally with low-angle banks and indirectly indicates the resistance of the bank to erosion and trampling. Streambank undercut and streamshore water depth were measured directly with a measuring rod.

Vegetation Form

Vegetation overhang is the distance living vegetation from 0 to 30 cm above the stream surface overhangs the water column. This overhang provides fish cover and is related to the species of plants in the riparian corridor. Vegetation overhang was measured directly with a measuring rod. Streambank stability is a measure of relative cover, in percent, that was determined by visually estimating the amount of vigorous vegetal cover (basal area) or composition of large, stabilizing inorganic particles on the bank. This variable can further describe the vigor of the vegetation and its ability to protect the streambank from erosion.

Livestock Influence

Vegetation use was estimated visually near the end of the grazing season along each transect line to determine the amount of forage removed by livestock during the preceding grazing season. This estimate incorporated an estimate of the amount of vegetative productivity lost through past grazing (e.g., in trailing and watering areas). Thus, an area released from grazing may continue to show use if substantial bare ground remains as a result of heavy past grazing. Streambank alteration evaluated the amount, in percent, that streambanks have diverged from their optimal natural condition. Estimating alteration is inherently subjective and imprecise but provides insight into the mechanics of changes in channel structure induced by external forces, that, on Big Creek, include livestock.

Statistical Treatment

Basic statistical analysis was performed using SAS for Personal Computers, Version 6 (SAS Institute 1985a, 1985b, 1985c)[5]. Raw data from each transect were sorted by stream edge community type and mean values for each environmental variable by community type were computed. Frequency of each community type, which was also the sample size from which each mean was calculated, was also determined. Due to the consequent reduction in sample sizes from the sorting process, differences between means were not tested for statistical significance. Higher level grouping of streamside structure was accomplished by using the cluster analysis module in SYSTAT (Wilkinson 1986). Average structural and vegetal form characteristics by community type were arranged in a matrix and clustered by single (nearest neighbor) and complete (farthest neighbor) linkages, and dendrograms reflecting their degree of structural similarity (based on Euclidean distance) were produced.

Results

Community Type Frequencies

Grazed sites generally contained about the same mix of community types as did their adjacent ungrazed sites, but proportions of each type differed (Table 2). This was particularly true in the Lower Big Creek study area, where the ungrazed site had had 15 years of protection from grazing.

Lower Big Creek Study Area.—The lower grazed site (site 1) contained fewer individual community types than either of the other two sites. Sites 2 (ungrazed) and 3 (grazed) each contained one unique community type; these discrepancies, however, involved only relatively infrequent types. Mineral-based community types dominated the two grazed sections (66.4 and 62.6%, respectively) but were infrequent (6.7%) within the ungrazed site (Figure 3). At least three of the occurrences of ROCK community types (2.5%) and two of the EB community types in the ungrazed site were attributable to the rock baskets anchoring the gabions that had been installed to improve trout habitat.

The decrease in mineral-dominated community types in the rested site (site 2) coincided with an increase in sedge-dominated types. Sedge-dominated community types accounted for only 3.3% of the community types in the lower grazed site and a minimal 1.6% of the waterside community types in the upper grazed site; however, they accounted for 32.5% of the community types in the ungrazed site. In the rested section of Lower Big Creek, which had been ungrazed for 15 years, sedge-dominated types were the second most abundant of the community types encountered at the water's edge. The ungrazed area included both the CARO and CANE community types, but only CANE was observed outside the exclosure.

Grassy herbaceous types, comprising chiefly POPR but including JUBA, were common in the grazed areas, where they constituted 25.4 and 30.9% of the community types in the upper and lower sites, respectively; in the rested area, however, they were codominants with CAREX and comprised 48.3% of the community types at the water's edge. Most of this increase in occurrence is attributable to the

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[4] A rigorous geomorphological definition of "streambank" has not been employed for the same reason that nonvegetated and vegetated CTs were not differentiated. Streambanks are technically the portion of the channel that restricts lateral movement of the stream. As these banks break down (i.e. increase in angle) they become less distinguishable from the channel bottom. The purpose of this paper is to evaluate these changes, especially at that point where the demarcation between channel and bank becomes blurred.

[5] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

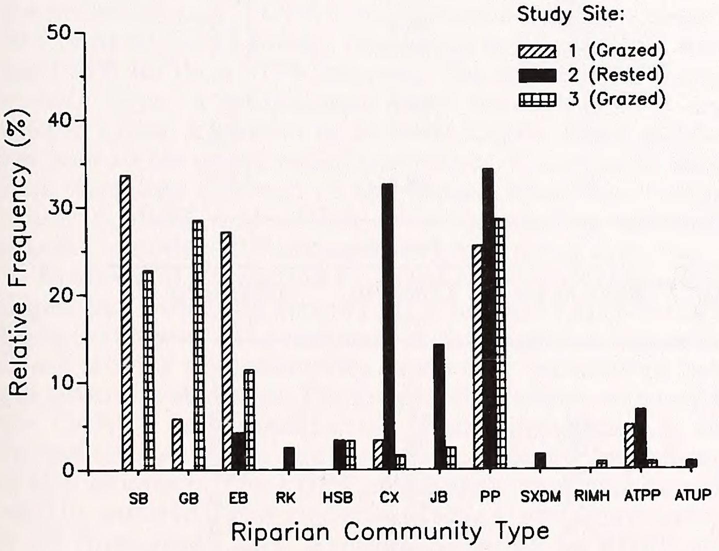
Table 2.—Distribution of observed riparian community types at water's edge in the Lower and Upper Big Creek study areas, Utah, in relation to grazing; N is the frequency of occurrence of each community type.

	Lower Big Creek						Upper Big Creek							
Community type[a]	Rested site		Lower site		Upper site		Grazed		Rested		Grazed		Rested	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
SB	0	0.0	41	33.6	28	22.8	15	12.3	13	10.8	1	0.8	9	7.4
GB	0	0.0	7	5.7	35	28.5	21	17.2	15	12.5	24	20.0	22	18.0
EB	5	4.2	33	27.1	14	11.4	37	30.3	15	12.5	6	5.0	7	5.7
ROCK	3[b]	2.5	0	0.0	0	0.0	—	—	—	—	—	—	—	—
HERB/SB	4	3.3	0	0.0	4	3.3	—	—	—	—	—	—	—	—
HERB/GB	—	—	—	—	—	—	0	0.0	0	0.0	6	5.0	5	4.1
AGST/SB	—	—	—	—	—	—	2	1.6	5	4.2	4	3.3	6	4.9
AGST/GB	—	—	—	—	—	—	0	0.0	1	0.8	0	0.0	3	2.5
CAREX	39	32.5	4	3.3	2	1.6	0	0.0	14	11.7	14	11.7	16	13.1
JUBA	17	14.2	0	0.0	3	2.4	0	0.0	0	0.0	2	1.7	11	9.0
MH	—	—	—	—	—	—	3	2.5	0	0.0	4	3.3	2	1.6
POPR	41	34.2	31	25.4	35	28.5	42	34.4	43	35.8	54	45.0	33	27.0
SALIX/DWM	2	1.7	0	0.0	0	0.0	0	0.0	0	0.0	2	1.7	3	2.5
SALIX/MH	—	—	—	—	—	—	0	0.0	0	0.0	3	2.5	5	4.1
RIBES/MH	0	0.0	0	0.0	1	0.8	—	—	—	—	—	—	—	—
ARTR/POPR	8	6.7	6	4.9	1	0.8	0	0.0	14	11.7	0	0.0	0	0.0
ARTR/UP	1	0.8	0	0.0	0	0.0	2	1.6	0	0.0	0	0.0	0	0.0
TOTAL	120	100.1	122	100.0	123	100.1	122	99.9	120	100.0	120	100.0	122	99.9

[a] Acronyms defined in Table 1.

[b] Rock baskets anchoring gabions.

Figure 3.—Distributions of riparian community types by study site, Lower Big Creek study area (acronyms shortened to fit on horizontal axis).



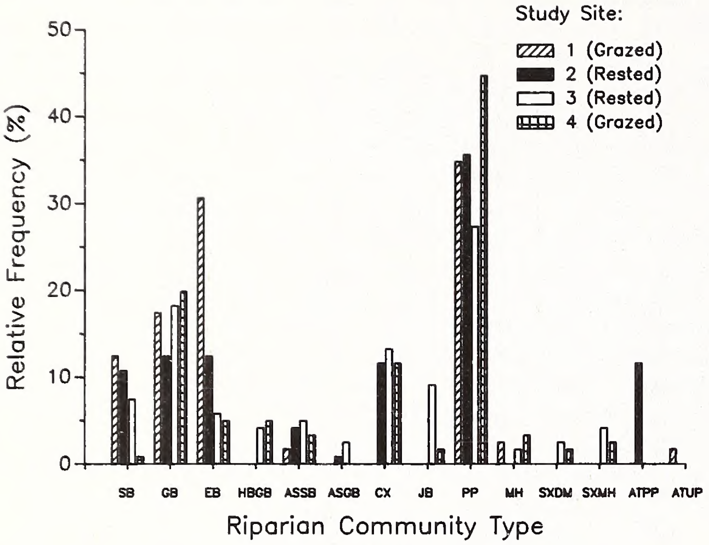
increased frequency of the JUBA community type in the ungrazed site; however, POPR was also more prevalent. Riparian shrub types were infrequent, and willow-dominated community types occurred only in the rested site. One occurrence of a community type defined by the presence of *Ribes inerme* (RIIN/MH) was recorded in the upper grazed site only.

Upper Big Creek Study Area.—Riparian community type differences between grazed and rested (4 years rest only) study sites were far less dramatic in the Upper Big Creek study area, but some progressive changes, paralleling those that were evident on Lower Big Creek, were noted nonetheless (Table 2, Figure 4). Mineral-dominated community types were somewhat less evident at water's edge in the ungrazed sites, and herbaceous mineral types, which may represent the initial phase of vegetal colonization of mineral bars, were more frequent. Sedge-dominated community types, here exclusively CANE, were not observed in the lower grazed site but were common in the lower rested site; they were slightly more abundant in the upper rested site than in the upper grazed site. Rush-dominated community types (i.e., JUBA) were not observed in the lower pair of sites but occurred in both upper sites. The POPR community type dominated the water's edge vegetation throughout but was least abundant in the upper rested site and most frequent in the upper grazed site. Riparian shrub community types were observed only in the upper study site pair, and upland types were noted only in the lower pair.

Community Type-Streambank Morphology Relationships

Streambank morphological characteristics by community type were evaluated only in the Lower Big Creek study area. Mean morphological attributes of the observed community types were quite different in the grazed sections than in the ungrazed site (Table 3). All morphological habitat characteristics except streamshore depth for the HERB/SB community type were clearly better for trout in the rested area. The cause of this apparent anomaly with

Figure 4.—Distributions of riparian community types by study site, Upper Big Creek study area (acronyms shortened to fit on horizontal axis).



HERB/SB may be attributable to the fact that few occurrences of this community type were observed and the potential for sampling error was therefore large.

Geomorphic Characteristics.—Average streamshore depth was typically much higher for each community type in the ungrazed portion of the Lower Big Creek study area than in the presence of grazing. Overall, streamshore depth was 133% greater under ungrazed conditions and achieved a maximum difference in the JUBA and ARTR/POPR communities, two community types that were relatively infrequent at the water's edge in the grazed sites. The POPR type, which was more evenly distributed over the entire study area and common in all three sites, had a 457% larger average shore depth in the ungrazed site.

Average streambank angle was lower within the rested site, and all community types that were common to Lower Big Creek sites had lower bank angles, on average, inside the exclosure. The differences in average bank angle between grazed and ungrazed sites ranged from 4% (HERB/SB) to 53% (EB and ARTR/POPR). The POPR communities, the most cosmopolitan of the community types encountered, had a 42% smaller average bank angle in the ungrazed site. In POPR community types, banks

Table 3.—Community type-specific comparison of mean streambank structural characteristics between grazing treatments, Lower Big Creek study area, Utah.

	Grazing treatment					
	Grazed			Rested		
Community type[a]	Extent (m)	Bank stability (%)	Stream-short depth (cm)	Extent (m)	Bank stability (%)	Stream-shore depth (cm)
SB	4.4	28.0	6.7	—	—	—
GB	9.1	46.4	16.6	—	—	—
EB[b]	1.3	29.4	4.0	1.0	89.0	14.6
ROCK	—	—	—	1.0	81.7	18.3
HERB/SB	4.6	60.0	16.2	3.0	100.0	14.6
CAREX	1.7	35.0	6.1	2.7	82.7	18.6
JUBA	1.5	32.5	0.0	1.6	85.3	16.2
POPR	3.1	29.6	2.1	2.8	93.8	11.9
SALIX/DWM	—	—	—	0.6	97.5	12.2
RIIN/MH	1.2	0.0	0.0	—	—	—
ARTR/POPR	3.0	17.1	0.0	3.0	88.8	13.7
ARTR/UP	—	—	—	3.0	90.0	8.2
Overall	4.1	32.0	6.4	2.5	88.5	14.9

	Grazed			Rested		
Community type[a]	Bank angle (°)	Undercut (cm)	Overhang (cm)	Bank angle (°)	Undercut (cm)	Overhang (cm)
SB	122	6.4	1.5	—	—	—
GB	95	13.7	2.1	—	—	—
EB	142	4.3	0.6	64	17.1	21.3
ROCK	—	—	—	62	25.3	25.3
HERB/SB	90	11.3	6.1	86	19.5	9.8
CAREX	116	10.7	2.1	74	17.7	14.9
JUBA	125	0.0	12.2	106	10.1	18.6
POPR	140	3.4	2.1	81	16.5	20.7
SALIX/DWM	—	—	—	50	24.4	25.9
RIIN/MH	170	0.0	0.0	—	—	—
ARTR/POPR	171	0.0	0.0	77	20.1	21.6
ARTR/UP	—	—	—	125	0.0	0.0
Overall	127	6.4	1.8	81	16.5	18.3

[a] Acronyms defined in Table 1.

[b] Rock baskets anchoring gabions.

were generally severely outsloped in the presence of grazing and insloped where protected from livestock. Even eroded banks (EB) exhibited small average bank angles in the rested site, but this was probably due largely to the fact that inside the exclosure they were mainly associated with the functioning artificial stream repair structures.

Because bank angles were much lower in the ungrazed site, average bank undercuts were much larger. The highest average angle was observed with ROCK, but the artificial nature of this community type in the Lower Big Creek study area (i.e., association with instream repair structures) trivializes its contribution. Similarly, large undercuts were observed in the rested site with EB communities, but their infrequency and association with artificial structures suggests that their apparently high quality is incidental. Of the major vegetative community types, POPR and CAREX provided the largest average undercuts, being 391% and 66% deeper, respectively, in the ungrazed site. The apparently large average streambank undercut for CAREX under grazing must be viewed with caution because of its relative infrequency but suggests that this community type is more resistant than POPR to shearing by grazing because of its sod-forming ability; however, the infrequency of CAREX in the grazed area suggests that once this community type begins to break down, it is readily lost from the system. The ARTR/POPR type, which appears to be transitional between riparian and upland vegetation (Platts and Nelson 1987) and may be a degraded riparian community type (B.L. Kovalchik, U. S. Forest Service, personal communication) exhibited dramatic differences in undercut; substantial undercuts occurred without grazing, but no undercut was noted with grazing.

Vegetative Characteristics.—Streambank stability is principally a function of vegetal cover, although large substrate particles must also be regarded as providing resistance to erosion and, therefore, stability. Average stability was much higher (177%) within the rested portion of the Lower Big Creek study area, a situation that was dramatically illustrated by the POPR community types. Outside the protected area, POPR communities averaged a meager 30% bank stability rating; inside the exclosure they averaged 94% stable, a 217% increase. The ARTR/POPR community type, a transitional type between POPR and upland types, appeared to be destabilized under grazing but was stable under rested conditions. Community types that were less common in the grazed area, most importantly CAREX and JUBA, revealed similar, although smaller, stability differences between grazing and rest.

Removal of vegetation by cattle reduces the amount of vegetation overhang directly, so it is hardly surprising to find greater average overhangs in the ungrazed Lower Big Creek site for all community types that occurred in both grazed and rested sites. The smallest difference occurred in the CAREX communities, but their infrequency in the grazed sites cautions against overstating the importance of this situation. The POPR community type was heavily used by cattle in the grazed sites (Table 4) and was common in all three study sites. Average overhang for POPR was nearly nine times (867%) greater, however, in the ungrazed site than in the grazed areas. Some community types, such as JUBA, which was the most heavily grazed community type but was also relatively rare in the grazed sites, had no overhang where grazing occurred.

Table 4.—Community type-specific comparison of mean vegetation use and total alteration between grazing treatments, Lower Big Creek study area, Utah.

Community type[a]	Grazing treatment			
	Grazed		Rested	
	Grazing use (%)	Alteration (%)	Grazing use (%)	Alteration (%)
SB	67	74	—	—
GB	71	53	—	—
EB	62	78	0	26
ROCK	—	—	0	28
HERB/SB	45	33	6	9
CAREX	32	61	0	26
JUBA	85	73	4	24
POPR	62	78	0	11
SALIX/DWM	—	—	0	13
RIIN/MH	20	90	—	—
ARTR/POPR	17	90	0	12
ARTR/UP	—	—	0	40
Overall	63	72	1	19

[a] Acronyms defined in Table 1.

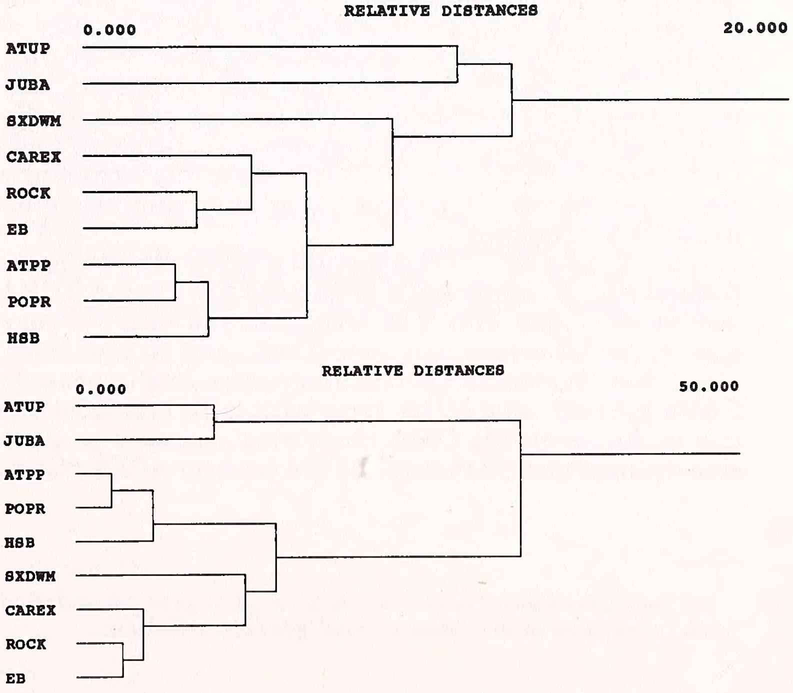
[b] Rock baskets anchoring gabions.

Higher Level Classification

Single linkage clustering, using all observed community types, produced only two distinct clusters, both joining at a relative similarity distance of about 5.0 (Figure 5a). The linkage suggests that the POPR, ARTR/POPR, and HSB community types function similarly with respect to maintaining bank quality, as do the CAREX, ROCK, and EB community types.

As is typical with complete linkage clustering, the apparent community type groupings discerned with this linkage technique are more compact than those discerned with single linkage clustering (Figure 5b). The overall pattern of the clustering is similar, but the SALIX/DWM type joins the CAREX-ROCK-EB cluster prior to linking with the POPR-ARTR/POPR-HSB group. The high bank quality of the SALIX/DWM type makes this an interesting linkage, although the rarity of this community type precludes drawing firm conclusions.

Figure 5.—Clustering of ungrazed community types based on bank characteristics: (a) single-linkage dendrogram, (b) complete linkage clustering.



Discussion

The ungrazed portion of the Lower Big Creek study area is vegetationally quite different from the nearby grazed areas, and a similar trend is becoming evident in the ungrazed treatments in the upper study area. The greatest differences concern the reappearance of *Carex*- and *Juncus*-dominated communities in conjunction with decreases in mineral-dominated communities within the ungrazed areas.

Although the soil wetness associated with sedge communities may discourage their use by cattle during certain parts of the grazing season and may account for their relatively low utilization in the grazed Lower Big Creek sites (32%), sedge-dominated community types are still far more abundant in the ungrazed portion of the Lower Big Creek study area and are apparently increasing in frequency in the ungrazed portions of the Upper Big Creek study area. In addition, there appeared to be an increase in width of streambank sedge community types and a shift from CANE to CARO (the latter being associated with more soil moisture) in parts of the lower exclosure, possibly indicating both increasing extent of sedge-dominated communities and a rising water table in certain areas. The presumed rise in water table within the exclosure is probably due to the reduction in water velocity, the increase in sediment deposition, and an increase in water level behind the instream repair structures. These structures remain functional within the ungrazed Lower Big Creek study site because they have been relatively undamaged by livestock. Outside the exclosure, however, where heavy grazing continues, most of the structures have been destroyed by livestock trampling and subsequent streambank erosion (Platts and Nelson 1985c).

Poa pratensis, a species that fares well under heavy grazing pressure, was common in all three Lower Big Creek study sites, but was slightly more abundant in the ungrazed site. Both *Juncus balticus* and *Poa pratensis* are generally considered "increaser"[6] species under grazed conditions. Our results do not refute this contention but suggest that both species may be less abundant under grazing than in areas that have been released from grazing (i.e. they continue to increase after grazing is removed), even after 20 years. In contrast to the sedge-dominated community types, the JUBA community type appears to be heavily used by livestock (85%) and is nearly absent from the grazed sites in both study areas. The low frequency of occurrence in the Lower Big Creek study area, where community type-specific use was measured, however, may mean that this apparently heavy level of use is strictly incidental. Our data suggest that removal of grazing leads to increase in JUBA at the water's edge; this community type is perhaps one of the first to appear on sandbars after livestock are removed.

The JUBA and POPR community types can be similar floristically; *P. pratensis* is frequently common in JUBA community types, and both bluegrass and rush are common in the SB community type (Platts and Nelson 1987). Thus, the reduction in SB with a corresponding increase in CAREX, POPR, and JUBA types within the ungrazed portion of the Lower Big Creek study area suggest a progressive change from SB through JUBA (and/or AGST/SB) to POPR on drier microsites, or to CAREX on wetter microsites (and possibly thence from CANE to CARO) during the first few years after release from grazing. The proposed mechanism behind this progressive or repair sequence is one of increasing soil moisture as increasing amounts of fine sediments are deposited and held on the developing bank, leading to narrowing of the stream channel and a corresponding rise in the water table. Conversely, the decrease in herbaceous mineral types in the upper rested site on Upper Big Creek and their absence from the ungrazed site on Lower Big Creek suggest that they may represent a regressive phase of the same sequence.

Another regressive/progressive sequence with POPR is also possible. Kovalchik (U. S. Forest Service, personal communication) suggests that the POPR/ARTR community type may represent degradation of POPR due to a lowered water table. As the channel widens and the banks recede, *P. pratensis* and *Artemesia tridentata* may form a transistional community type. If water tables and soil moisture increase, these two communities may return to POPR and from thence to other fully riparian types as determined by local factors. This is the process that seems to be occurring in the ungrazed sites.

Juncus balticus can produce thick, horizontal rhizomes (Cronquist et al. 1977). Youngblood et al. (1985) report that the JUBA community type in eastern Idaho and western Wyoming provides good sod- and bank-stabilizing properties, and POPR produces relatively unstable banks. The sod formed by JUBA adjacent to Big Creek appears to consist chiefly of vertically oriented root systems (Platts and Nelson 1987) that would intuitively seem to have little effect in counteracting bank shearing and sloughing forces imparted by cattle; however, this root structure may be typical only of early or degraded JUBA communities, with more vigorous root-systems possibly being produced later in the rehabilitative sequence. This study suggests that, in some cases, grazing may be relatively more injurious to POPR than to JUBA, the latter apparently maintaining better bank conditions under grazing, but that without grazing POPR provides superior streambank conditions.

Where sedges can become dominant, they clearly create the most optimal streambank structure. Even under grazed conditions, some of the optimum bank characteristics were associated with this community type. Thus, moderate grazing pressure after viable sedge communities have become reestablished may be acceptable, but the managers responsible must ensure that CAREX community types do not revert to less favorable communities like POPR. Both *Carex rostrata* and *C. nebraskensis* are capable of producing dense sod (Cronquist et al. 1977; Ratliff 1983), but our results suggest that only *C. nebraskensis* persists under the intensity with which Big Creek streambanks are grazed. Despite its resistence to grazing (Ratliff 1983; Ratliff and Westfall 1987), however, it appears that CANE community types are only poorly maintained under present grazing management. *Carex rostrata* may be less desirable to cattle than *C. nebraskensis* because of lower palatability and wetter habitat (Hermann 1970; Cronquist et al. 1977) and may therefore be additionally useful in deterring heavy grazing use in the riparian corridor if its requirements can be maintained or restored.

As these studies continue, we should be able to draw an increasingly clear picture of the general functioning of various community types in providing bank characteristics commensurate with riparian protection. We hope to be able to discern what community types produce optimum bank conditions and whether some types may be favored by limited grazing and still provide bank conditions similar to those provided by other, less grazing-resistant types. As managers interested in promoting the needs of both the livestock industry and the general public, we may, for example, be willing to sacrifice communities that do not fare well under grazing for some that do, provided their value for other uses remains nearly equivalent.

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[6] An increaser species is one that is favored by grazing and thus tends to increase in abundance under grazed conditions.

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Management Implications for Riparian Dominance Types of Montana

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Abstract.—A classification of Montana's riparian plant communities, based on dominant species, was developed by the Montana Riparian Association. The dominance-type approach allows land managers to identify, inventory, and map riparian communities and provides basic management information for each type. One weakness of the dominance type classification is the broad and overlapping range of environments spanned by individual dominance types. However, the dominance type classification is only the first product in development of a complete ecological classification of riparian vegetation and sites. Continuing work will provide a better understanding of successional and site relationships of the dominance types.

Current emphasis on improving the management of riparian areas indicates the need for more readily available ecological and management information concerning these areas. An immediate need existed for a classification system that would enable land managers to recognize, inventory, and map riparian communities (Pfister and Batchelor 1984). A summary of current management knowledge for each of the riparian communities was also needed. A grant from the Montana Department of Natural Resources and Conservation in 1985 and formation of the Montana Riparian Association (a cooperative of private and public organizations) in 1986 were aimed at meeting these needs. The initial efforts led to a classification of riparian vegetation based on dominant species utilizing a statewide data base of 1817 plots (Hansen et al. 1988a). This classification represents the first product of a cooperative effort to better understand and manage riparian areas of Montana.

Dominance types have been described as the lowest level in a national wetland classification hierarchy (Cowardin et al. 1979). Riparian dominance types are named simply by the single species currently having the greatest canopy cover (subject to a minimum of 25% canopy cover to qualify) in the tallest layer of a riparian community (Hansen et al. 1988a). They include vegetation dominated by tree, shrub, or herbaceous species. Dominance types are essentially equivalent in concept to cover types used in the broad-scale classification of forest vegetation (Eyre 1980). A dominance type often spans a range of environments, and it may occur in both riparian and upland situations, as in the case of Ponderosa pine *Pinus ponderosa* or quaking aspen *Populus tremuloides*.

Table 1.—Distribution of riparian dominance types by life form groups.

Formation class	Formation subclass	Dominance types	Sample plots
I. Forest and woodland	A. Broad-leaved Deciduous	10	248
(>4.9 m tall)	B. Needle-leaved Evergreen	13	281
II. Shrub-scrubland	A. Broad-leaved deciduous	27	438
(<4.9 m tall)	B. Needle-leaved evergreen	2	6
III. Herbland	A. Forbs	32	95
	B. Grasses	25	222
	C. Sedges	26	372
	D. Rushes	11	139
	E. Ferns and Fern Allies	4	16
IV. Altered Environments	A. Non-native vegetation	Not Sampled	
	B. Non-vegetated	Not Sampled	
	TOTALS	150	181

Content of Dominance Types

A dominance type classification is primarily descriptive. After sample plots in a data base are assigned to the types, available information is summarized in a standard form for each type. A total of 150 riparian dominance types have been identified and described. The number of types can be arranged by life form groups (Cowardin et al. 1979) (Table 1). The published description of each dominance type (Hansen et al. 1988a) included dominant species, physical setting, community description (associated species), physical site description (soils, water relations), and successional status. Management information included timber productivity, forage production for livestock, forage production for wildlife, fisheries value, hydrologic characteristics (bank stability, compaction, flooding), fire, revegetation potential, and recreational uses and considerations. The first source of information was the published literature. Secondly, observations from the data base were interpreted and summarized. Thirdly, distribution of the draft publication to land managers (through the Montana Riparian Association) encouraged additions and revisions based on field experience.

Management Applications

One of the first requirements for using a vegetation classification is to correctly identify the species. In our publication, this process was aided by providing illustrations, taxonomic descriptions, and a special key to each of the riparian dominance type species.

An important use of the dominance type classification is in the preparation of maps following field identification of dominance types. An example of this application was provided when the Montana Riparian Association conducted a reconnaissance inventory of riparian dominance type occurrence on 11 major rivers of southwestern Montana (Hansen et al. 1987). Dominance types found along

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the reaches of each river were identified and summarized by river segments. This provided an overview of community composition useable for broad-scale land use planning and management activities.

Another major mapping project was initiated in 1988 for 256 km of the Missouri River. Individual polygons were first delineated on aerial color photographs based on landscape position, photo texture, and color. This was followed by intensive field verification of each polygon and supplemental collection of vegetation, soils, and management information. This map will be used by the U. S. Bureau of Land Management for current land use planning and management activities.

The use of dominance types for specific management planning purposes can be illustrated by another example. During an inventory of a grazing allotment in central Montana, the sandbar willow *Salix exigua* dominance type was observed to be common on sand and gravel bars immediately adjacent to a stream that bisected the pasture. By referring to the dominance type description, the land manager learned that this type: (1) is subject to annual flooding, (2) has low to moderate forage productivity (depending on the density of sandbar willow stems), and (3) the value of this type as wildlife cover is high. The ability of sandbar willow to rapidly colonize and stabilize alluvial deposits indicated that stands should be maintained and encouraged, rather than removed or heavily grazed.

Streambanks along one reach of the stream were found to be in poor condition. Planting rooted cuttings of willow stems was chosen as a rehabilitation method. Methods for establishing sandbar willow are found in the dominance type description. However, if vegetative overhang for fisheries habitat is one of the objectives, then another species may be more appropriate (sandbar willow has an upright rather than a spreading growth form). Grazing management plans for the area would need to provide protection for the willows during the establishment period.

Another possible use for dominance types is to describe successional relationships. For instance, will one dominance type change to another due to natural plant succession, flooding, grazing or other disturbance? The answer to this question (if known) will be found in each individual type description. Some dominance types represent short-lived, ephemeral communities; others represent relatively permanent communities. A number of dominance types, such as Kentucky bluegrass *Poa pratensis* represent a modified condition (disclimax) due to the strong influence of another factor, such as heavy livestock grazing. Often a single dominance type will occur as an early successional stage on a wet site and a late successional stage on a drier site.

Current Research Objectives

Although the dominance types represent a "quick fix" to the question of riparian vegetation classification, they represent only an initial step in developing a complete ecological classification. Current research by the Montana Riparian Association is moving beyond the dominance types to develop a classification based on vegetative site potential, similar to the habitat type approach widely applied to the grassland, shrubland, woodland and forest vegetation of the Rocky Mountain region. Several wetland habitat types have been defined for Montana (Pfister et al. 1977; Mueggler and Stewart 1980). However, flood plains and many stream-side areas were not included in their sampling.

In June 1988, an ecological site type classification for southwestern Montana riparian lands was distributed for field testing and review (Hansen et al. 1988b); work on a similar classification for eastern Montana will be available in the spring of 1989.

Fundamentally, our concepts and terminology build upon the widely accepted plant association and habitat type approach (Daubenmire 1952), with some modifications to handle riparian environments that may change in a relatively short period of time. As in central Oregon (Kovalchik 1987), the latest successional stage for a given environment is termed a "riparian association" and major earlier successional stages are termed "community types". This modification of the "community type" approach (e.g. Youngblood et al. 1985) provides a more refined distinction of successional and environmental relationships. The "riparian site type" is then defined as the area of land occupied or potentially occupied by a specific riparian association.

Dominance Types and Ecological Site Types

As classifications based on site potential are developed, the dominance type approach will remain useful for describing existing conditions. For example, if dominance types have been documented (inventory or maps), they could be subdivided by riparian site types to recognize different environments. On the other hand, if riparian site types are documented (inventory or maps), they could be subdivided by dominance types to illustrate major differences in current vegetation.

Some riparian dominance types are equivalent to riparian associations. This is illustrated by several herbaceous and shrubby species that are capable of maintaining "monospecific" dominance, (essentially the sole species occurring on a site). For example, beaked sedge *Carex rostrata*, a common sedge in Montana, forms long-lived, stable communities, persisting until a dramatic change in the water regime occurs. Once established, the dense network of rhizomes formed by beaked sedge may limit the abundance of most other species to only scattered individuals.

Numerous dominance types may also be associated with a single riparian site type, with the dominance types changing in both time (succession) and on different locations within one riparian site type. For example, Geyer willow *Salix geyeriana*, Booth willow *S. boothii*, and Drummond willow *S. drummondiana* dominance types often occur together in a patchy mixture within a single riparian site type. Therefore, management implications for these dominance types may be similar.

Finally, a single dominance type may span numerous riparian site types. This is commonly true with forest dominance types because of their broad ecological amplitudes. This represents one of the greatest weaknesses of the dominance type approach to vegetation classification; a large number of site types and successional stages may be represented by a single dominance type. Furthermore, because dominance types are based only on current dominant species, they will change over time because of natural or man-caused disturbance and succession.

Although the dominance-type approach has several weaknesses relative to classifications based on site potentials, the dominance types provide land managers with an immediate, useful tool for the general classification and inventory of riparian communities. Sole use of either vegetation-based dominance types or site types are insufficient for ecosystem classification. When combined, however, they provide a powerful tool for describing both existing and potential vegetation. Together they provide a strong foundation for developing, testing, and communicating management techniques and experiences.

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Forest Practices and Riparian Management in Washington State: Data Based Regulation Development

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Abstract.—In the past, forest practice regulations for riparian zones in Washington have been based primarily on political, rather than scientific, considerations. In 1986 a new process, called Timber, Fish and Wildlife, attempted to formulate regulations based on technical data. Separate regulations were devised for eastern and western Washington due to the differences between the two regions in vegetation, climate, and timber management strategies. In western Washington, where clear-cutting is the predominant harvest method, regulations were based on existing data on large organic debris (LOD) loading in channels coupled with simulation models of stand dynamics. The regulations were designed to provide for the maintenance of LOD at the levels observed in streams in old-growth timber. Data for eastern Washington riparian zones were collected specifically for the purpose of designing new regulations. Uneven-aged management is the most common silvicultural technique practiced in this area. Information was collected on riparian stand characteristics and LOD size and frequency in streams. Regulations were designed to maintain LOD levels observed in unmanaged stands and were based on a relationship between stand density and LOD frequency. Wildlife needs were addressed by providing sufficient numbers of larger trees to generate snags, provide desired levels of canopy cover and maintain a multi-storied canopy.

Forest practices in Washington State were drastically altered in January 1988, as a result of the implementation of a negotiated agreement called the Timber Fish and Wildlife Agreement, or TFW. A prototype of this process of natural resource management through consensus was available: the negotiations between Washington State and northwest Indian tribes over a series of salmon harvest management plans through the early and mid 1980s. Participants in the negotiations producing the TFW agreement included the Washington State Departments of Fisheries, Wildlife, Natural Resources and Ecology, Indian tribes, timber companies, nonindustrial forest-land owners, and environmental groups. The core of the agreement was an understanding between the participants that public resources must be protected while at the same time enabling economically-viable timber management.

The groups involved in the negotiations leading to the TFW agreement were willing to participate because all felt there were shortcomings in the existing forest practice regulations. The timber industry had been faced with recurring regulatory changes that compromised their ability to schedule timber harvest and forest management activities. The state agencies, Indian tribes, and environmental groups felt the public resources were not receiving adequate protection.

The TFW agreement dealt not only with riparian zones, but provided regulatory and voluntary guidelines for road construction and maintenance, cumulative effects, upland management areas, temperature and sediment control, and a method for correcting past forest practices impacts. This paper will focus only on those aspects of the TFW process relating to the management of riparian areas. The majority of the riparian regulations developed during negotiation of the TFW agreement apply only to fish bearing waters. Intermittent streams and waters without fish populations do not require riparian management zones under the present forest practices. However, there are studies in progress to determine if these systems have been afforded adequate protection.

A set of primary goals was established for riparian zone management. The goals, as stated in the agreement were as follows: "The fisheries resource goals are long-term habitat productivity for natural and wild fish, and the protection of hatchery water supplies. The wildlife resource goal is to provide the greatest diversity of habitats (particularly riparian, wetlands, and old growth), and to assure the greatest diversity of species within those habitats for the survival and reproduction of enough individuals to maintain the native wildlife of Washington's forest lands. The water quantity and quality goals are protection of water needs of people, fish and wildlife. The timber resource goal is the continued growth and development of the state's forest products industry which has a vital stake in the long-term productivity of both the public and private forest land base. The archeological and cultural goals are to develop a process to inventory archeological/cultural spaces in managed forests; and to inventory, evaluate, preserve and protect traditional cultural and archeological spaces and assure tribal access."

It was the responsibility of the Riparian Regulations Committee to use available technical information to formulate rules that would meet these goals. However, it was recognized that the lack of technical information on some topics would necessitate basing the regulations on untested assumptions. Therefore, the TFW process created a research and monitoring program to determine the effectiveness of the regulations and test the assumptions that were made during their formulation. Contributions have been made by all TFW participants to the research effort, augmented by appropriations from the state legislature. This research effort was then coupled with an adaptive management procedure that enables regulations to be altered as information becomes available.

The institution of the research and monitoring effort was a critical feature of the TFW agreement. This process provided an avenue for resolution of points on which the participants could not reach consensus. An interim rule was usually agreed upon for these items, and they were then referred to the research and monitoring process for resolution through cooperative research on the topic. In order to minimize disagreements over the applicability of new data to the regulations, most research is cooperative, with two or more of the participating parties involved, and the approval of the entire process. Thus, all parties have a vested interest in the information collected and are familiar with the strengths and weaknesses of the data. It is envisioned that through this process regulations will be refined to provide adequate environmental protection and minimize unwarranted restrictions on timber harvest and management.

The first priority of the Research and Monitoring Committee was to identify a series of projects that would evaluate some of the assumptions made in formulating the regulations and assess the overall effectiveness of the new rules. The projects identified that relate to management of riparian areas include:

(1) Determination of riparian stand characteristics before and after timber harvest on a statewide bases.

(2) Determination of large organic debris (LOD) recruitment rate in clear-cut and selectively harvested stands.

(3) Monitoring of fish habitat following timber harvest.

(4) Development of habitat/fish use relationships.

(5) Evaluation of LOD addition to streams as a site-specific, riparian management option.

(6) Development of predictive temperature models and evaluation of biological response to temperature.

(7) Evaluation of effectiveness of regulations on smaller (first- and second-order) streams that do not have significant fish populations.

(8) Development of a predictive tool to relate riparian stand characteristics to canopy cover.

(9) Evaluation of the relationship between LOD size and its ability to affect stream morphology.

(10) Assessment of wildlife habitat conditions and use of riparian zones.

Work is currently underway on most of these projects.

Development of Riparian Management Regulations

Forest practice regulations for riparian areas in Pacific Northwest states historically have focused on maintaining shade and minimizing sediment and forest chemical introduction to the stream during forest management activities (Washington Forest Practices Board 1976; Oregon Department of Forestry 1985). However, recent research has indicated that the presence of large pieces of wood in streams is key to maintaining productive fish habitat (Bisson et al. 1982; Tschaplinski and Hartman 1983; Lisle 1986). Since this aspect of riparian management had not been addressed in previous regulation packages in Washington, the Committee focused on developing standards that would maintain a source of large wood for the stream and incorporate provisions to protect water quality.

In order to develop regulations that would provide for wood input to streams, a target level for amount of wood in wood input to streams, a target level for amount of wood in stream channels had to be established. Data were available on the amount and characteristics of LOD in streams flowing through old-growth timber in some areas of western Washington. This information was utilized as a basis for developing estimates of the appropriate number of trees that should remain standing along streams in western Washington after harvest. Quantitative information on habitat requirements of wildlife in the riparian zone was generally unavailable. Therefore, those aspects of the regulations designed specifically to meet wildlife needs were based on the opinion of local experts.

Due to the geographical limitations of the information on which the western Washington riparian regulations were based, we recognized that they might not be appropriate for areas of the state displaying different environmental conditions or where harvest methods other than clear-cutting are used. There are large differences in climate, vegetation, hydrological regime, and timber harvest methods between the wetter timberlands of western Washington and the more arid lands east of the Cascade Mountains. Recognition of these differences prompted the development of two separate sets of riparian regulations.

In recognition of the fact that conditions in riparian zones in Washington may vary widely, an option was included in the regulations that permits any operator to develop a site-specific plan for any type of activity in the riparian zone, if the proposed action provides protection for non-timber resources equal to or better than that afforded by the regulations. The appropriateness of any plan deviating from the regulations is determined by a group of individuals with expertise in various aspects of resource management, termed an "interdisciplinary team". Membership on these teams varies according to the situation being considered and the availability of qualified personnel. The site-specific plan option of the riparian regulations is viewed as being critical to the ultimate success of the process since it builds a great deal of flexibility into the system and enables it to adapt to virtually any conditions which might be encountered.

Western Washington

Knowledge of two variables is essential in formulating effective regulations aimed at providing for the continued input of stable debris to streams: how much debris is required and the characteristics of stable debris for a given stream. The amounts of LOD necessary to provide "optimum" levels for any stream ecosystem function are not known and certainly vary widely from one system to another. However, information was available on LOD amounts in streams flowing through undisturbed, old-growth forests for a series of streams in southwestern Washington (Bilby 1988) and the Olympic Peninsula (J. Cederholm, personal communication).

The LOD density varied as a function of stream size, with a sharp decrease in the frequency of wood as streams increase in size (Figure 1). This pattern is likely caused by the increased capacity for larger streams to move bigger pieces of wood downstream. A difference in LOD frequency was also observed between streams with predominantly gravel and cobble substrate and those systems with beds composed of larger materials; the latter streams contain approximately half the LOD found in similar-sized streams with finer substrate (J. Cederholm, personal communication). Average piece size of wood in the channels was also seen to increase as stream size increased (Figure 2). Again, this relationship is due to the increased capacity for larger systems to move bigger pieces of wood.

Figure 1.—Relationship between channel width and frequency of occurrence of pieces of woody debris for systems in southwestern Washington. The curve has the equation log^{10} frequency = 1.12 log^{10} width + 0.46; r^2 = 0.68 (from Bilby 1988).

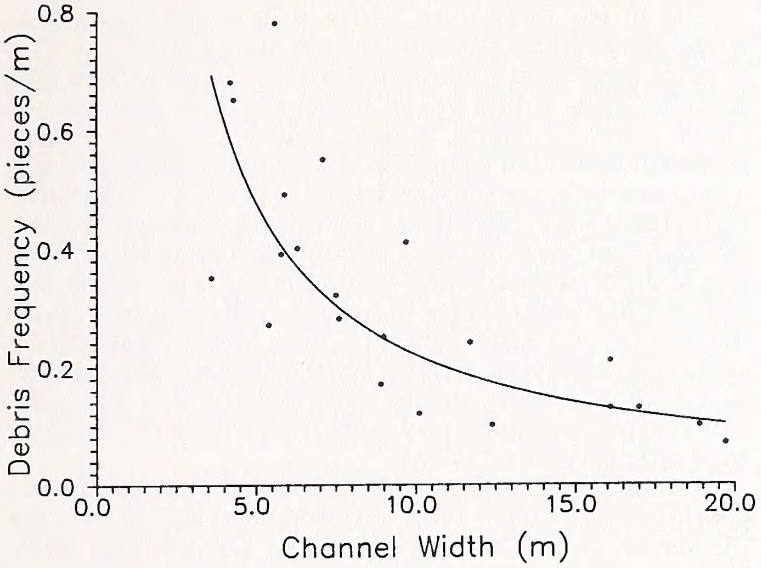
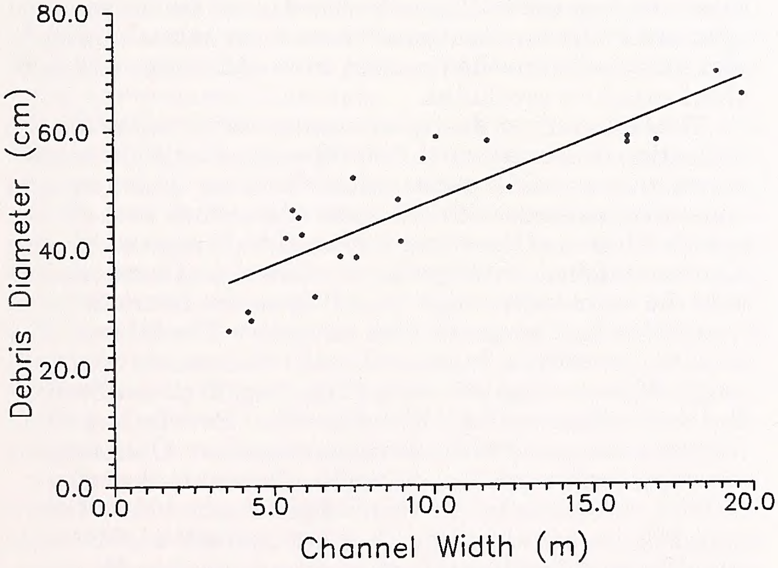


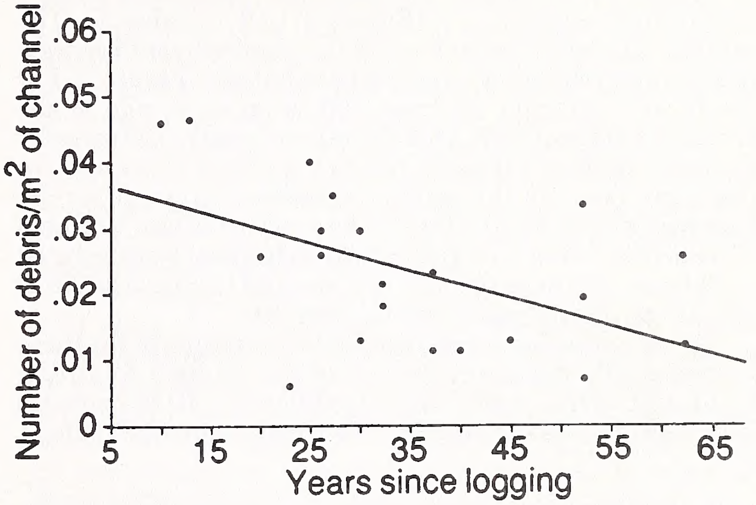
Figure 2.—Relationship between channel width and mean debris diameter for systems in southwestern Washington. The curve has the equation diameter = 2.14 width + 26.43; r^2 = 0.76 (from Bilby 1988).



The amount of wood in a stream ultimately depends upon its rate of input and disappearance. The rate of disappearance of LOD for streams on the Olympic Peninsula (Figure 3) is about 1%/year (Grette 1985). Information on the input rate of wood from a streamside zone after timber harvest of adjacent areas was not available. However, we estimated the input rate based on average stem density and size in second growth stands (Hall et al. 1985) and some assumptions about the rate at which these trees would enter the stream after harvest of the adjoining area.

Using the available data and our assumptions on input rates, we were able to estimate the number of trees required to maintain the LOD levels found in old-growth systems. Due to the observed relationships between stream size and LOD frequency and size, different sets of requirements were developed for each of four stream channel-width categories; > 23 m, 15-23 m, 2-15 m, and < 2 m. In addition, we separated streams with gravel/cobble beds from those with boulder/bedrock beds, based on the observation of lower LOD frequency in those systems with coarser substrate.

Figure 3.—Relationship between number of pieces of woody debris from an old-growth stand and the years since logging of that stand occurred for sites on the Olympic Peninsula of Washington. The curve has the equation pieces of large organic debris (LOD) remaining = 0.00042 years since harvest + 0.038; r = -0.51 (from Grette 1985).



An average second-growth stand at harvest age would contain approximately 500 stems/hectare, with an average diameter at breast height (DBH) of 45 cm (Hall et al. 1985). Mortality would affect approximately 25% of the trees remaining along the stream over the next 70-year rotation (Hall et al. 1985). In addition, we estimated, based on observations of Committee members, that an additional 25% of the trees would contribute wood to the channel due to the increased risk of blowdown over this time interval. The validity of the assumption is currently being evaluated. We limited the number of pieces supplied by a single tree to one, although very often a tree will contribute multiple pieces of LOD to a channel, especially in smaller streams.

Larger pieces of wood are required in larger streams. Average piece diameter for the two largest channel width categories were calculated at 65 cm and 75 cm. Trees remaining along the stream were estimated to reach this size at 25 and 35 years after harvest, respectively. Therefore, contribution to LOD levels in the stream from the riparian zone would not occur until this time. The trees remaining along the stream after harvest are large enough to supply stable wood to the two smaller stream size classes at harvest.

Trees planted or sprouting after harvest within the riparian zone would reach a size sufficient to contribute LOD to the two smaller channel-width categories during the 70-year period after harvest. For the smallest streams, young trees are large enough to supply LOD approximately 20 years after the harvest, but for the next larger size class, pieces would not be of sufficient size to make a contribution until 60 years after harvest. Because of the older timber remaining in the streamside area after harvest, it was assumed that density of young trees would be about half that which would normally be observed during regeneration of a cleared area. Thus, the stand would thin from

370 stems/hectare at age 20 to 250 stems/hectare at age 70 (Hall et al. 1985). Input of this material was limited to trees located within 15 m of the channel, due to the relatively short length of the younger trees.

We estimated appropriate levels of trees to be left along each of the four channel-width categories using the formula: Target LOD density = (Input from remaining trees) + (Input from regrowth) + (Residual LOD) (Table 1). The target LOD densities for each of the channel-width categories were estimated by a regression analysis (Figure 1). For the largest streams, 50 trees/305 m on each side of the channel were required. This value increased to 100 trees for the next smallest category, due to the observed increase in piece frequency in the smaller systems (Figure 1). As the regrowing trees were able to make a contribution, numbers of trees remaining along stream after harvest were reduced to 75 trees/305 m in the 2-15 m class and to 25 trees/305 m for the smallest channel-width category.

The estimated frequency of LOD in streams in the three largest width classes at the end of the rotation following institution of the regulations all exhibited LOD frequencies in excess of the levels seen in old-growth systems (Table 1).

Table 1.—Values used to formulate riparian tree requirements for western Washington streams and estimated values of large organic debris (LOD) frequency 70 years after application of the regulations. Values in the row labeled "Years after harvest to reach stable size" indicate the time needed for the average tree left in the riparian zone after harvest to reach a size sufficient to produce pieces of wood with diameters equal to the average piece measured in streams of similar size flowing through undisturbed areas (Figure 1). Values listed in the row entitled "Years until input from new stand" indicates the length of time necessary before trees planted or germinated in the riparian zone after harvest can provide stable pieces of wood to the channel.

	Channel width (m)			
	> 23	15-23	2-15	< 2
Old-growth LOD frequency (pieces/m)	0.03[a]	0.11[b]	0.26[b]	0.60[c]
Mean diameter of stable LOD (cm)	75	65	45	20
Years after harvest to reach stable size	35	25	0	0
Years until input from new stand	—[d]	—[d]	60	20
Estimated LOD at end of rotation				
Residual in-channel LOD (pieces/m)	0.01	0.03	0.08	0.18
Input from leave trees (pieces/m)	0.08	0.21	0.25	0.08
Input from new stand (pieces/m)	0	0	0.04	0.18
Total LOD at end of relocation (pieces/m)	0.09	0.24	0.37	0.44

[a] Data from Cederholm (personal communication).

[b] Data from Bilby (1985).

[c] Estimated values.

[d] Trees regenerated after harvest do not reach sufficient size during the ensuing rotation to contribute LOD to streams in these size categories.

The smallest stream size class shows levels somewhat lower than those seen in undisturbed situations. However, in these very small streams, branches or tops from trees left along the stream are often large enough to provide stable debris and this form of input may increase the LOD frequency sufficiently to make up the estimated deficit.

Size of the leave trees varies with stream size class. Along the smallest streams, the remaining stems must be 15 cm or larger and 30 cm or larger along streams from 2-15 m wide. These values are less than the mean diameter of stable pieces of debris in these systems, but since they represent minimum values, the average size tree remaining would approximate the size needed to provide stable material to the stream. For the two largest size classes of stream, the diameter distribution of remaining trees is representative of the distribution present on the site prior to harvest. This requirement ensures that some of the largest trees on the site remain after harvest. These larger trees will be capable of supplying suitably sized material to the channel sooner than smaller stems. Theoretically, this approach will also produce some very large trees within the riparian zone after several rotations.

A number of studies have indicated that coniferous debris persists longer than hardwood material in streams (Anderson et al. 1978; Swanson and Lienkaemper 1978; Keller and Tally 1979). In order to ensure that conifer trees would not be eliminated from some riparian zones, ratios of conifer/hardwood leave trees were established. Retention of a species composition representative of that present on the site prior to harvest was instituted for the two largest channel-width categories. For channels from 2-15 m wide this value was set at 2/1 and reduced to 1/1 for the smallest systems. In those situations where these ratios cannot be met, removal from the riparian zone of the type of tree in short supply is precluded.

The boundary of the riparian zone varies, following the transition from wetland to upland vegetation at those sites where true riparian zones exist. In cases where upland vegetation extends to the channel edge, zones were set at 8 m on each side of the stream. A maximum zone width was also established, in response to concerns of land owners that the regulations might result in severe restrictions on timber harvest in areas with extensive floodplains. The maximum widths increased with increasing channel width. These values were set at 8 m, 15 m, 23 m, and 30 m for the four channel-width categories. Provisions were included to expand these zones as necessary to encompass swamps, bogs, marshes, or ponds adjacent to the stream.

The provisions in the regulations to provide sufficient standing timber along the stream to maintain LOD levels should also aid in the protection of water quality. However, several additional stipulations were added to the rules to help ensure that sediment and temperature levels would not damage aquatic resources. Minimizing sediment delivery to the channel from or through the riparian zone depends, in large part, on avoiding disturbance to soils within this area. Transport of significant amounts of sediment to streams requires overland flow. Most forest soils possess infiltration capacities high enough that overland flow is a rare phenomenon in undisturbed situations. In order to protect this property of the soil in the riparian area, any use of yarding equipment within the zone must be approved by the Department of Natural Resources and damage to understory vegetation must be avoided. In addition, bank and bed stability were protected by requiring that woody debris embedded in the channel or bank not be disturbed during yarding operations, felled trees not enter the water, trees with root systems stabilizing the bank not be cut, and high stumps be left when needed to prevent felled timber from rolling into the water.

In situations where a potential problem with water temperature is perceived, provisions are included in the regulations to require either 50% or 75% of the pre-harvest shade to remain along a stream after logging, depending upon the degree of sensitivity of the system to elevation of water temperatures. Research is presently ongoing to produce a process to identify temperature sensitive streams and to assess the effectiveness of the regulations at mitigating water temperature increases.

The need for large trees by some species of wildlife may not be met in managed forests. In order to provide some of this habitat, the 12 largest trees per hectare zone are left.

The data used in developing these regulations were collected from a restricted geographical area. Systems with significantly different vegetation, hydrologic regimes, or geologic composition are likely to exhibit considerable deviation from the values on which the regulations were based, as proved to be the case when data was gathered on streams in eastern Washington. The inclusion in the regulation package of a provision for research and adaptive management enables the rules to be continuously updated as new information is obtained.

Eastern Washington

During the summer and autumn of 1987, data were collected on a series of stream sections east of the Cascade Mountains for the purpose of obtaining information on which technically justifiable regulations could be based. This information was collected as a cooperative effort between state agencies, Indian tribes, timber companies, and environmental groups.

A total of 72 stream sections was examined during this process. Sites were located on forest lands throughout the eastern half of Washington state. Sites in unmanaged areas and in locations from which trees had been selectively harvested in the recent past were examined. A range of stream sizes, from the smallest fish-bearing stream up to sections with channels in excess of 20 m were surveyed. The length of the sections varied but generally included at least 50 pieces of LOD and extended a minimum of 150 m. Sites heavily impacted by mass failures or showing evidence of effects of off-site influences that might have influenced LOD, such as an upstream bridge, were avoided.

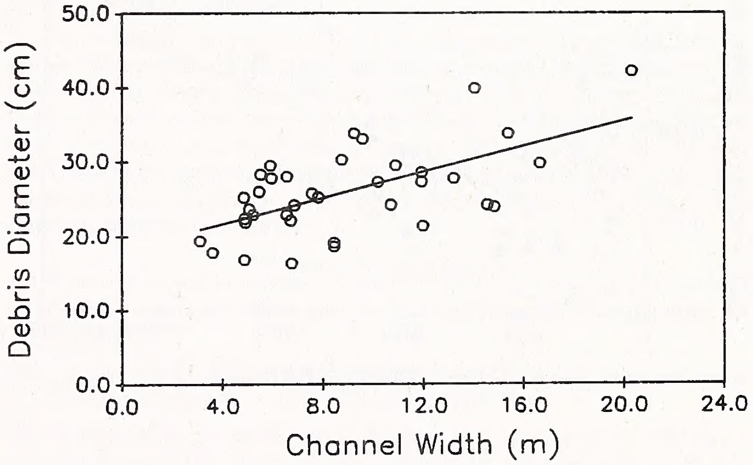
Data gathered on each stream included bankfull channel width and gradient, measured every 15 m. A visual estimate of the percent of the bed material in each of four size categories was made (gravel and finer < 6 cm; cobbles 6-25 cm; boulders > 25 cm; and bedrock). Diameter, length in the channel, and length out of the channel for each piece of woody debris was measured and the species of tree that produced the piece was identified.

Data on the riparian system bordering the surveyed streams was gathered by establishing four to six plots at 20-m intervals on alternating sides of the stream. The plots were 6-m wide and extended 30 m perpendicular to and upslope from the channel's edge. The diameter, height, and species of each tree with a diameter over 10 cm was recorded within each plot.

The LOD frequency at unmanaged sites in eastern Washington ranged from 0.11 pieces/100 m to 0.61 pieces/100 m, which are similar to the values for western Washington (Figure 1). However, the frequency of LOD in eastern Washington streams was not related to stream size, unlike the pattern seen in western Washington. The difference between the two areas is likely due to two factors: (1) there was enormous variation in tree density in unmanaged riparian areas along the eastside streams, ranging from 105 stems/hectare to nearly 1,800 stems/hectare; due to the more homogeneous climatic conditions prevailing in western Washington, it is likely that variability in stand density is less, and (2) hydrologic conditions in eastern Washington probably display smaller extremes than on the west side, due to the fact that most high discharges in eastern Washington are governed by snowmelt runoff, versus heavy winter rains or rain on snow on the west side of the Cascades. Therefore, a stream in western Washington might have a greater capacity to flush wood from the channel than a stream displaying a similar channel width in eastern Washington.

There was a relationship between the average diameter of a piece of LOD and the size of the stream in which it occurred (Figure 4). This is similar to the pattern observed in western Washington, but piece size was smaller in eastern Washington streams than in similar sized systems west of the Cascades. Likely reasons for this pattern relate to the production of larger pieces of wood by west side forests and differences in hydrologic conditions.

Figure 4.—Relationship between channel width and mean debris diameter for sites in eastern Washington. The curve has the equation diameter = 0.87 width + 18.20; $r^2 = 0.37$).



We also observed a significant difference (t-test $P < 0.05$) in LOD frequency between gravel/cobble and boulder/bedrock bedded streams at both managed and unmanaged sites (Figure 5). This pattern was consistent with that seen in western Washington. As a result, predominant substrate size was used to stratify stream reaches for regulatory purposes. There was no significant difference (t-test $P > 0.05$) observed in LOD frequency between the managed and unmanaged sites for either substrate condition (Figure 5).

A relationship was also observed between density of trees in the streamside area and LOD frequency (Figures 6 and 7). These relationships were used as the basis for determining the number of standing trees needed to sustain levels of LOD in eastern Washington streams similar to those observed in undisturbed systems. All proposed riparian regulations for eastern Washington were evaluated by applying the suggested treatment to the streamside areas inventoried during our survey, determining the number and sizes of trees present after harvest and esti-

Figure 5.—Frequency of occurrence of pieces of woody debris in streams with different substrate characteristics and management histories. Error bars indicate 95% confidence intervals.

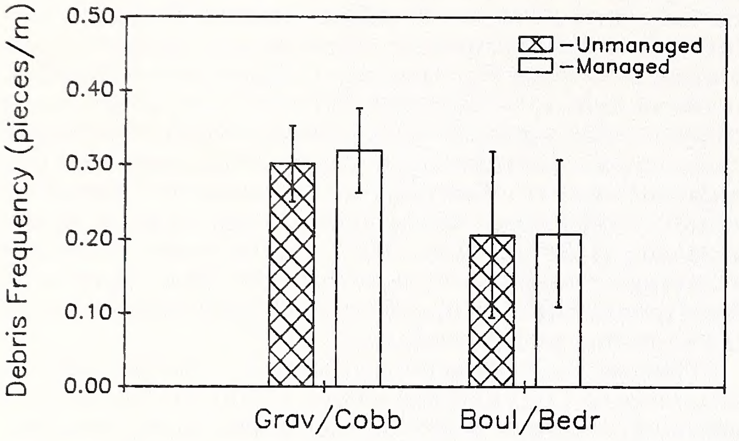


Figure 6.—Relationship between tree density in the riparian area and large organic debris (LOD) frequency in the stream for sites in eastern Washington with gravel/cobble beds. The curve has the equation LOD frequency = 0.0003 tree density + 0.151; $r^2 = 0.41$.

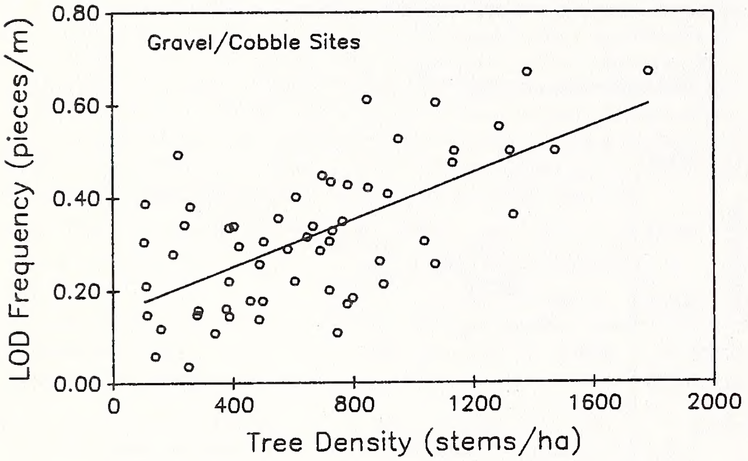


Figure 7.—Relationship between tree density in the riparian area and large organic debris (LOD) frequency in the stream for sites in eastern Washington with boulder/bedrock beds. The curve has the equation LOD frequency = 0.0003 tree density + 0.116; $r^2 = 0.31$.

mating the resultant LOD frequency from the regression in Figures 6 and 7.

In view of the great variability in stand density, riparian regulations for eastern Washington were constructed in such a way that average leave tree requirements would be met on a majority of the sites, but enough flexibility would be built into the system to enable some harvest of timber to occur on those sites which naturally exhibit very low tree densities. However, to ensure that no locations would be harvested to the point where non-tiber resources would be unacceptably compromised, minimum riparian stand densities were established below which harvest is precluded. These levels were set at 335 stems/hectare for gravel/cobble streams and 185 stem/hectare for boulder/bedrock systems.

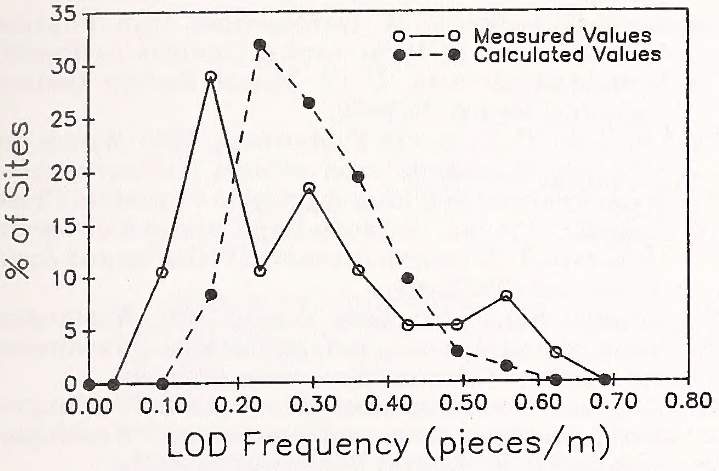
Unlike the regulations in western Washington, the eastern Washington rules do not set numbers of trees to be left in the riparian zone after harvest. This approach was selected in response to the very large variability in riparian conditions we observed during our surveys. All trees with diameters less than 30 cm will be left. In addition, 40 conifers/hectare between 30 cm and 50 cm and 7 conifers/hectare over 50 cm will remain after harvest. Twelve hardwood trees/hectare in excess of 30 cm diameter will also remain on the site, when available. All snags on the site which do not violate state safety standards will also be left.

The width of the riparian management zone for eastern Washington streams also varies somewhat from the widths required in western Washington. Riparian areas managed in association with a selective cut of the upland area will range from a minimum of 9 m to a maximum of 15 m on each side of the stream, with the boundary following the change in vegetation type from riparian to upland between these two extremes. Riparian areas managed in association with clear-cutting will average 15 m in width on each side of the stream and may range from a minimum of 9 m to a maximum of 90 m. The wider riparian zone along clear-cut sites was designed to compensate for elimination of LOD input to the channel from areas outside the defined riparian zone. At selectively harvested sites, a substantial number of trees remain standing outside the riparian zone after cutting and may contribute wood to the channel.

Applying these regulations to the sites surveyed during our study and using regression analysis (Figures 6 and 7), the estimated amount of LOD provided by the post-harvest stand will maintain the distribution seen in unmanaged stands (Figure 8). The calculated distributions seem to indicate that there will be fewer sites with very high or very low levels of LOD after harvest. However, these changes are largely an artifact of using the regressions to approximate LOD amounts. Nonetheless, the regulations appear to provide a satisfactory amount of LOD. Based on our data, the regulations would preclude harvest in riparian zones at 18.2% of the boulder/bedrock sites and 21.3% of the gravel/cobble sites. Along streams where harvest would be permitted, relatively few trees would be removed, with 87% of the pre-harvest stems remaining in the riparian zone after harvest at gravel/cobble sites and 81% at boulder/bedrock sites.

Aspects of the riparian management regulations developed for western Washington to address water temperature and sedimentation also apply to eastern Washington. Sediment input is minimized through limitations on heavy equipment usage, minimizing road construction, felling timber away from the stream, and maintaining bank and bed integrity. Entry of silvicultural chemicals into the water is managed through the establishment of buffers on

Figure 8.—Comparison of the frequency distribution of large organic debris (LOD) levels measured at unmanaged sites surveyed in eastern Washington and estimated values for all sites after harvest under the new regulations. The estimated values were based on the regression in Figures 6 and 7.



all water. It was also assumed that due to the relatively few trees that will be taken from streamside areas under these rules, that shading of the channel should be sufficient to prevent excessive increases in water temperature. All these assumptions are currently being evaluated as part of the ongoing research and monitoring effort associated with the TFW agreement.

Several features of wildlife habitat in riparian areas were emphasized during development of the eastern Washington riparian regulations. Particular attention was focused on retention and future recruitment of snags to maintain viable populations of cavity nesting animals, provision of coniferous canopy cover of 50% to 70% for thermal refuge, and retention of the vertical structural diversity of the vegetation.

Analysis of the data collected during the eastern Washington riparian study suggests that the regulations will provide most of these function. Retaining all stems less than 30 cm in diameter will provide a large number of small snags, contribute to canopy closure, and constitute the lower canopy layers. Requirements for leaving larger stems (40 conifers/hectare between 30 cm and 50 cm in diameter, 7 conifers/hectare greater than 50 cm in diameter, and 12 deciduous trees/hectare greater than 30 cm in diameter) will produce larger snags, provide year-round thermal buffering and form the upper canopy layers.

Riparian Zone Tree Requirements

The core of regulations produced from the above procedures are the requirements for the number, sizes, and species of trees to remain along streams after harvest. These rules are excerpted from the Washington Forest Practices Rules and Regulations (Table 2) (Washington Forest Practices Board 1988).

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Table 2.—Requirements for numbers of trees to be left along streams in western and eastern Washington after timber harvest.

Western Washington

Water type and average width[b]	RMZ maximum width	Ratio of conifer to deciduous/ minimum size of leave trees	Number of trees/ 305 m each side	
			gravel/ cobble[a]	boulder/ bedrock
1 and 2 Water 23 m and over	30 m	representative of stand	50 trees	25 trees
1 and 2 Water under 23 m	23 m	representative of stand	100 trees	50 trees
3 Water 2 m and over	15 m	2 to 1/ 30 cm or next largest available[c]	75 trees	25 trees
3 Water less than 2 m	8 m	1 to 1/15 cm or next largest available	25 trees	25 trees

[a] Gravel and cobble streambeds are composed, predominately, of material < 25 cm in diameter.

[b] Washington water typing system is based on domestic water use, fish use, and size of streams. A detailed description of the criteria may be found in Washington Forest Practices Rules and Regulations (Washington Forest Practices Board 1988).

[c] "Or next largest available" requires that the next largest trees to those specified in the rule be left standing when those available are smaller than the sizes specified. Ponds or lakes which are type 1, 2, or 3 waters shall have the same leave tree requirements as boulder/bedrock streams.

For wildlife habitat within the riparian management zone, leave an average of 12 undisturbed and uncut wildlife trees per hectare at the ratio of 1 deciduous tree to 1 conifer tree equal in size to the largest existing trees of those species within the zone. Where the 1 to 1 ratio is not possible, then substitute either species present. Forty percent or more of the leave trees shall be live and undamaged on completion of harvest. Wildlife trees shall be left in clumps, whenever possible.

Eastern Washington

(A) Leave all trees 30.5 cm or less in diameter breast height (DBH).

(B) Leave all snags within the riparian management zone that do not violate the state safety regulations.

(C) Leave 40 live conifer trees/hectare between 30.5 cm DBH and 50.8 cm DBH distributed by size as representative of the stand.

(D) Leave 7 conifer trees/hectare 50.8 cm DBH or larger.

(E) Leave the 5 largest deciduous trees/hectare 40.6 cm DBH or larger. Where these deciduous trees do not exist, and where 5 snags/hectare 50.8 cm in DBH or larger do not exist, substitute 12 conifer trees/hectare 50.8 cm in DBH or larger. If conifer trees of 50.8 cm DBH or larger do not exist within the riparian zone, then substitute the 5 largest conifer trees/hectare.

(F) Leave 7 deciduous tree between 30.5 cm and 40.6 cm DBH where they exist.

(G) On streams with a boulder/bedrock bed, the minimum leave tree requirement shall be 185 trees/hectare 10.2 DBH or larger.

(H) On streams with a gravel/cobble (less than 25.4 cm diameter) bed, the minimum leave tree requirement shall be 335 trees/hectare 10.2 cm DBH or larger.

(I) On lakes and ponds the minimum leave tree requirement shall be 185 trees/hectare 10.2 cm DBH or larger.

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Cattle Behavior with Emphasis on Time and Activity Allocations Between Upland and Riparian Habitats[1]

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Abstract.—Cattle distribution and behavior were studied in riparian and upland habitats at Fort Bayard in southwestern New Mexico. The study area was a pinyon *Pinus* spp.-juniper *Juniperus*-blue grama *Boutelova gracilis* savannah with numerous drainages and intermittently flowing streams. A three-pasture seasonal rotation grazing scheme with a moderate stocking rate was employed after 47 years of no livestock grazing. Radio telemetry and vibracorders were used to collect location and behavior data. Data were collected through one dormant and two growing seasons. Seasonal patterns in habitat use were well defined. Habitat use shifted from heavy use on riparian areas during the growing season to virtually no riparian use during the dormant season. Riparian use was also influenced by pasture changes. Riparian observations increased significantly ($P < 0.05$) during the first collection in a new pasture. During the dormant season, open-upland and browse-upland were selected. Behavior varied with season. Time spent grazing and distance travelled were greatest during the summer months and least during the winter months.

Riparian habitats are those assemblages of plants, animals, and aquatic communities whose presence can be attributed either directly or indirectly to factors that are induced by or related to streams. They are unique and distinct from surrounding upland communities (Kauffman and Krueger 1984).

Resource management agencies have recognized the importance of riparian habitats. For example, Peterson (1983) stated the position of the U. S. Forest Service as: "Riparian areas are among the most productive, sensitive, diverse, and often the most geographically limited ecosystems within national forest lands. Range, watershed, and wildlife improvement programs give high priority to the restoration of riparian areas."

Historically, livestock grazing has been an ubiquitous use of western forest and rangelands, including riparian habitats. Cattle often exhibit a strong preference for riparian habitats (Platts and Nelson 1985). The main attributes of riparian areas believed to attract and hold cattle include the availability of water, shade, thermal cover, and the quality and variety of forage (Ames 1977; Severson and Boldt 1978).

The objective of this study was to compare daily and seasonal distribution and behavior patterns of cattle in riparian habitats with those in associated vegetation types.

Study Area

The study was conducted on the Fort Bayard Administrative Site, Gila National Forest, located 16 km east of Silver City in southwestern New Mexico. Originally set aside as a military reservation in 1869, Fort Bayard was subjected to year-long continuous grazing until 1937. Expensive restorative actions were taken in 1937 that included the exclusion of all livestock except for a few pack and saddle animals. The Gila National Forest assumed management of Fort Bayard in 1941 and maintained the livestock exclusion policy until 1984, when this study was initiated. Topography is composed of fairly level bench lands with small knolls with elevations from 1,800 to 2,000 m. Numerous drainages and permanent springs are found throughout, creating a number of streams that flow intermittently. Average annual precipitation at the lower elevations is approximately 40 cm/year with an addition of about 5 cm/year for each 150-m increase in elevation.

Upland soils are Lithic and Lithic Vertic Haplustolls, whereas Aquic Haplustolls are most common in lowland areas (Severson 1986). Where topography is gentle, soils are deep and have good fertility and a high water-holding capacity. Soils on steeper terrain are shallow, less fertile, stony, and have a low water-holding capacity. Vegetation is primarily pinyon pine *Pinus edulis* and juniper *Juniperus* spp. overstory with a shrub midstory and perennial grasses in the understory. Overstory and midstory species become very dense at higher elevations. There are numerous patches of open grassland at lower elevations.

Methods

Forty-four Hereford cows were managed as one herd in a three-pasture rotation system (Figure 1): Twin Sisters (548 hectares), Barrel Springs (301 hectares), and Whiskey Creek (484 hectares). The herd was rotated every 4 months for 20 months. The study was initiated at the start of the 1984 growing season and terminated at the end of the 1985 growing season. Three collections were made during the 4 months animals were in each pasture (total of 14). Data were gathered for 4 consecutive days during each period. Collections were planned so the first would be done 7 to 10 d after introduction of the herd into a pasture. Second and third collections were conducted approximately 45 d after introduction and 10 d prior to removal, respectively.

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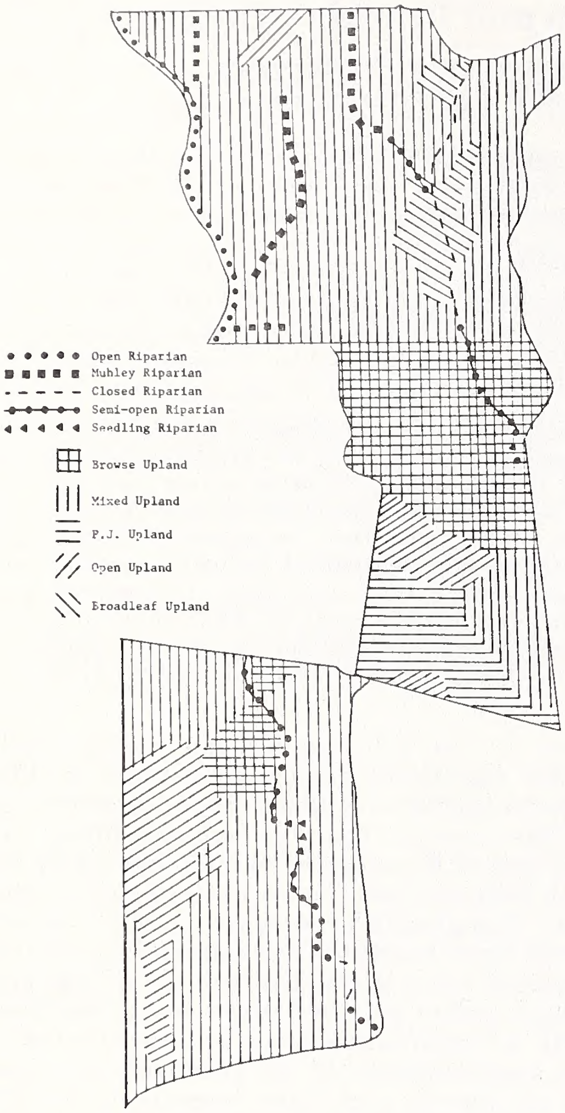
[1] This study was conducted in cooperation with the Rocky Mountain Forest and Range Experiment Station. Appreciation is given to the Gila National Forest, Silver City District for technical assistance. This study is published as Journal Article No. 312, Agricultural Experiment Station, Las Cruces, NM 88003-0003.

Figure 1.—Vegetation-type map for the study area.



Behavior data were gathered using radio collars and vibracorders. Ten radio collars were used, with activity sensing mercury tip switches. The tip switch activated either of two pulse rates corresponding to head posture. Ten degrees above parallel (head up) pulsed at 650 ms, conversely 10° below parallel (head down) pulsed at 900 ms. Two antenna sites were located in or near each pasture. To reduce the error associated with transferring field observations to map locations, antenna base plates were trued with pasture maps each time an antenna was set at a site.

Location

Simultaneous observations from paired antenna sites were taken on all ten animals every hour for 12 to 14 h each day during the 4-d collection periods. Observations were normally collected during daylight hours, with several late night, early morning, and 24-h collections. Whenever possible, telemetry readings were checked by visual observations. Accuracy of field observations were also tested using transmitter beacons that were set at several locations featured on the map. All observations were plotted on pasture maps and overlays were used to determine animal location as to habitat and vegetation types.

Behavior

Behavior data also were collected using radio telemetry equipment. After location readings were taken on all collared animals, receiving equipment was set to record the tip switch pulse rate on a chart recorder. This would indicate whether the animal was grazing, resting, or traveling. Pulse rate was recorded for approximately 10 min for each hour on all animals whose signals were strong. Vibracorders mounted on aluminum collars were attached to the necks of four cows at the start of each collection. At the end of the collection period, instruments were removed and the data recorded. This indicated activity of the animal continuously for about 150 h.

Habitats

Vegetation boundaries were delineated for each pasture (Figure 1) within habitat types (Table 1). Both vegetation and habitat types were used to analyze location information collected with the radio telemetry equipment. Since pasture rotation occurred on a seasonal basis: Twin Sisters (late growing season), Barrel Springs (dormant season), Whiskey Creek (early growing season), it was impossible to separate seasonal influences from pasture influences. All pastures were adjacent to one of the other pastures. With a few exceptions, all three contained the same vegetation types, although they occurred in different proportions. Because of pasture similarity and time allowed for acclimation of animals in new pastures before a collection, season was considered most influential in determining cattle behavior and distribution.

Distribution of animals within grazing periods was of particular interest. Telemetry and vibracorder data were used to establish grazing periods. A grazing period was defined to include only those hours of the day in which 50% or more of the observations were classified as grazing. Two periods were thereby defined: 0600 to 0900 hours, and 1200 to 2000 hours. Bonferroni Simultaneous Confidence Intervals were used (Byers et al. 1984) to place confidence intervals on the proportion of observations occurring within a designated area (actual use), which in turn was compared to expected use, to determine if actual and expected use were inclusive. Chi-square was used to analyze data (SAS 1984). All statistical references were made at $P = 0.10$, unless otherwise noted.

Results and Discussion

Cattle demonstrated distinct seasonal distribution patterns among habitats (Table 2). Shifts in habitat use occurred from disproportionately heavy on riparian areas during the growing season to virtually no use during the dormant season. This resulted from a lack of green vegetation within riparian habitats during the dormant season compared to upland habitats which contained evergreen browse species.

Behavioral data were not collected until 7 d after cattle were rotated into a new pasture to allow them time to acclimatize to the pasture. There was an increase in riparian observations between the last collection in a pasture and the first collection in the succeeding pasture. Similar findings have been reported by Roath and Krueger (1982a). This occurred during moves between the dormant season pasture (Barrel Springs) and the early growing season pasture (Whiskey Creek), and between the early growing season pasture and the late growing season pasture (Twin Sisters). There was a decrease in riparian use at the start of

Table 1.—Vegetation types delineated for the study.

Type	Description
Open riparian	Riparian areas without a woody overstory. Vegetation includes cool season grasses Gramineae, sedges *Carex* spp., and sweet clover *Trifolium* spp.
Semi-open riparian	Riparian areas with a semi-open canopy (one or more trees within 100 m) made up of one of several trees species. The understory is made up of cool season grasses, sedges, and sweet clover.
Closed riparian	Riparian areas with a closed canopy (interlocked branches) of tree species. Associated understory is very sparse and mainly sedges.
Seedling riparian	Riparian areas that have concentrations of cottonwood *Populus* spp. and/or willow *Salix* spp. seedlings at a height susceptible to grazing. Associated vegetation is similar to open riparian with cool season grasses, sedges, and sweet clover.
Muhly riparian	Riparian areas dominated by bull muhly. Occurs in steep, narrow, and rocky drainages.
Open upland	Upland areas free of woody vegetation. Warm season grasses dominate these areas.
Browse upland	Upland areas with a shrub mid-story. Most of this vegetation type was created by the mechanical removal of pinyon *Pinus* spp. and juniper *Juniperus* spp. Herbaceous vegetation is warm season grasses.
Mixed upland	Upland areas with an overstory of pinyon and juniper, a mid-story of browse species, and a sparse understory of warm season grasses.
P. J. upland	Upland areas with an overstory of pinyon and juniper and an understory of warm season grasses.
Broadleaf upland	Upland areas without an overstory or a mid-story. Broadleaf herbaceous vegetation along with warm season grasses dominate.

Table 2.—Comparison of riparian observations (percent) between collections within pasture and year.

Collection	Whiskey Creek pasture	Twin Sisters pasture[2]	Barrel Springs pasture	Whiskey Creek pasture	Twin Sisters pasture
Early	—[1]	14.29^{ab}	0.79	11.49^{a}	34.89^{a}
Middle	13.04^{a}	17.25^{a}	3.45	2.62^{b}	23.76^{b}
Lake	5.18^{b}	6.48^{b}	3.94	4.17^{c}	12.83^{b}

[1] Data not collected.

[2] Percentages in a column with different superscripts differ ($P < 0.05$). Only daylight (0500 to 2000 hours) observations were considered.

grazing when cows were moved from the late season pasture to the dormant season pasture. Apparently, cows were utilizing palatable regrowth in riparian habitats on the late growing season pasture, but when moved to the dormant season pasture, they selected browse species over the rank and dormant forage in the riparian habitat (Neel et al. 1989).

Behavior periods and distribution within these periods were defined. Riparian habitat observations (Table 3) were greater than expected during early and middle collections (July and August 1984, 1985) in Twin Sisters pasture and early and middle collections (March 1985 and May 1984, respectively). None was less than expected for riparian habitats, although the Barrel Springs early collection (November 1984) and middle collection (January 1985) were conspicuously absent. Some animal activity in riparian habitat, although minimal, occurred in Barrel Springs during the early and middle collection (Table 2). Since these observations did not occur during grazing periods, they may represent watering or traveling.

Observations on upland habitats were inverse to riparian habitats. In all but two collections, this was reflected in the mixed upland vegetation type that had observations less than expected (Table 3). The two collections for which this was not true were the late collection (June 1984) and the early collection (March 1985) in Whiskey Creek pasture.

Observations in the closed riparian vegetation type during Twin Sisters late collection (October 1984) were greater than expected even though overall riparian habitat activity was not different. No riparian vegetation type had fewer observations than expected.

Overall, during the late growing season (July through October), riparian vegetation types were used for grazing and these consisted of open, semi-open, and closed riparian. During the dormant season (November through February), open and browse uplands were preferred vegetation types. No distinct pattern occurred during the early growing season (March through June).

Simultaneous confidence intervals parallel seasonal distribution patterns with riparian habitat having a greater than expected use during July and August of both years. Use of riparian habitat also was greater than expected in May of 1984 and March of 1985. This activity was apparently a result of the greening-up of cool season grasses and spring annuals resulting from monthly rainfall totals of 2.49 cm and 3.20 cm, respectively.

There was less consistency of use between collections and years in vegetation types within the riparian habitat. Similarly, Pinchak (1983) found certain vegetation types were preferentially selected within pasture and year. He also noted that although patterns were present, dispersion and distribution were affected by both year and pasture and were not uniform. Such inconsistency was observed in Twin Sisters pasture. During July 1984, riparian observations were spread evenly between open and semi-open riparian types and neither was significant. By August livestock were concentrated in the open riparian type and observations were greater than expected. The following year, during July, riparian observations were spread between three vegetation types (open, closed, and muhly) and all were greater than expected; again there was a change by August. Activity in muhly riparian was not significant, leaving open and closed riparian as the selected vegetation types. In the riparian habitat, only open riparian was common to all four collections.

Observations in the closed-riparian type were only greater than expected during the summer of 1985. Since

Table 3.—Bonferrioni simultaneous confidence intervals for vegetation and habitat types. Based on observations during grazing periods (those periods in which 50% or more of the individuals were grazing).

Pasture/Collection Vegetation type	n	Expected usage	Actual usage	Bonferroni intervals for actual usage
Whiskey Creek 1984				
Middle collection				
Open riparian	1	0.015	0.011	$0 < P < 0.038$
Semi-open riparian	12	0.013	0.129 [a]	$0.044 < P < 0.214$
Closed riparian		0.003		
Seedling riparian	1	0.003	0.011	$0 < P < 0.038$
Open upland	20	0.197	0.215	$0.111 < P < 0.319$
Browse upland	10	0.067	0.108	$0.030 < P < 0.186$
Mixed upland	49	0.699	0.527 [b]	$0.400 < P < 0.654$
Total riparian	14	0.034	0.151 [a]	$0.078 < P < 0.224$
Total upland	79	0.963	0.850 [b]	$0.777 < P < 0.923$
Late collection				
Open riparian		0.015		
Semi-open riparian	2	0.013	0.014	$0 < P < 0.038$
Closed riparian		0.003		
Seedling riparian	6	0.003	0.041	$0.001 < P < 0.081$
Open upland	13	0.197	0.088 [b]	$0.031 < P < 0.145$
Browse upland	3	0.067	0.020 [b]	$0 < P < 0.048$
Mixed upland	123	0.699	0.837 [a]	$0.762 < P < 0.912$
Total riparian	8	0.034	0.055	$0.018 < P < 0.092$
Total upland	139	0.963	0.945	$0.908 < P < 0.982$
Twin Sisters 1984				
Early collection				
Open riparian	6	0.028	0.078	$0.003 < P < 0.153$
Semi-open riparian	6	0.006	0.078	$0.003 < P < 0.153$
Closed riparian		0.012		
Muhly riparian	1	0.023	0.013	$0 < P < 0.045$
Open upland	1	0.013	0.013	$0 < P < 0.045$
Mixed upland	58	0.853	0.753	$0.633 < P < 0.873$
Broadleaf upland	5	0.058	0.065	$0 < P < 0.134$
Total riparian	13	0.069	0.169 [a]	$0.085 < P < 0.253$
Total upland	64	0.924	0.831 [b]	$0.747 < P < 0.915$
Middle collection				
Open riparian	32	0.028	0.201 [a]	$0.123 < P < 0.279$
Semi-open riparian		0.006		
Closed riparian		0.012		
Muhly riparian	10	0.023	0.063	$0.016 < P < 0.110$
Open upland	23	0.013	0.145 [a]	$0.077 < P < 0.213$
Mixed upland	94	0.853	0.591 [b]	$0.495 < P < 0.687$
Broadleaf upland		0.058		
Total riparian	42	0.069	0.264 [a]	$0.195 < P < 0.333$
Total upland	117	0.924	0.736 [b]	$0.677 < P < 0.805$
Late collection				
Open riparian		0.028		
Semi-open riparian	1	0.006	0.006	$0 < P < 0.020$
Closed riparian	10	0.012	0.058 [a]	$0.014 < P < 0.102$
Muhly riparian	4	0.023	0.023	$0 < P < 0.051$
Open upland		0.013		
Mixed upland	140	0.853	0.809	$0.763 < P < 0.882$
Broadleaf upland	18	0.058	0.104	$0.047 < P < 0.161$
Total riparian	15	0.069	0.087	$0.045 < P < 0.129$
Total upland	158	0.924	0.913	$0.871 < P < 0.955$
Barrell Springs 1984				
Early collection				
Open riparian		0.012		
Closed riparian		0.002		
Seedling riparian		0.005		
Open upland	6	0.012	0.086	$0.004 < P < 0.168$
Browse upland	39	0.500	0.557	$0.412 < P < 0.702$
Mixed upland	10	0.148	0.143	$0.040 < P < 0.246$
P.J. upland	15	0.222	0.214	$0.094 < P < 0.334$
Total riparian	0	0.019	0.000	
Total upland	70	0.982	1.000	

Table 3. (continued)—Bonferroni simultaneous confidence intervals for vegetation and habitat types. Based on observations during grazing periods (those periods in which 50% or more of the individuals were grazing).

Pasture/Collection Vegetation type	n	Expected usage	Actual usage	Bonferroni intervals for actual usage
Middle collection				
Open riparian		0.012		
Closed riparian		0.002		
Seedling riparian		0.005		
Open upland	26	0.112	0.199[a]	$0.114 < P < 0.284$
Browse upland	72	0.500	0.550	$0.444 < P < 0.656$
Mixed upland	9	0.148	0.069[b]	$0.015 < P < 0.123$
P.J. upland	24	0.222	0.183	$0.100 < P < 0.266$
Total riparian	0	0.019	0.000	
Total upland	131	0.982	1.000	
Late collection				
Open riparian	1	0.012	0.007	$0 < P < 0.024$
Closed riparian	1	0.002	0.007	$0 < P < 0.024$
Seedling riparian	2	0.005	0.014	$0 < P < 0.038$
Open upland	36	0.112	0.257[a]	$0.167 < P < 0.347$
Browse upland	88	0.500	0.629[a]	$0.529 < P < 0.729$
Mixed upland	6	0.148	0.043[b]	$0.001 < P < 0.085$
P.J. upland	6	0.222	0.043[b]	$0.001 < P < 0.085$
Total riparian	4	0.019	0.028	$0.001 < P < 0.055$
Total upland	136	0.982	0.972	$0.945 < P < 0.999$
Whiskey Creek 1985				
Early collection				
Open riparian	4	0.015	0.021	$0 < P < 0.046$
Semi-open riparian	9	0.013	0.047	$0.010 < P < 0.084$
Closed riparian	1	0.003	0.005	$0 < P < 0.017$
Seedling riparian	1	0.003	0.005	$0 < P < 0.017$
Open upland	35	0.197	0.181	$0.113 < P < 0.249$
Browse upland	6	0.067	0.131[b]	$0 < P < 0.062$
Mixed upland	137	0.699	0.710	$0.630 < P < 0.790$
Total riparian	15	0.034	0.078[a]	$0.044 < P < 0.116$
Total upland	188	0.963	0.922[b]	$0.884 < P < 0.960$
Middle collection				
Open riparian	4	0.015	0.023	$0 < P < 0.051$
Semi-open riparian	1	0.013	0.006	$0 < P < 0.020$
Closed riparian		0.003		
Seedling riparian		0.003		
Open upland	73	0.197	0.417[a]	$0.326 < P < 0.508$
Browse upland	2	0.067	0.011[b]	$0 < P < 0.030$
Mixed upland	95	0.699	0.543[a]	$0.451 < P < 0.635$
Total riparian	5	0.034	0.029	$0.004 < P < 0.054$
Total upland	170	0.963	0.971	$0.946 < P < 0.996$
Late collection				
Open riparian	1	0.015	0.009	$0 < P < 0.031$
Semi-open riparian	2	0.013	0.018	$0 < P < 0.049$
Closed riparian		0.003		
Seedling riparian	2	0.003	0.018	$0 < P < 0.049$
Open upland	28	0.197	0.257	$0.154 < P < 0.360$
Browse upland	1	0.067	0.009[b]	$0 < P < 0.031$
Mixed upland	75	0.699	0.688	$0.579 < P < 0.797$
Total riparian	5	0.034	0.045	$0.006 < P < 0.084$
Total upland	104	0.963	0.954	$0.915 < P < 0.993$
Twin Sisters 1985				
Early collection				
Open riparian	35	0.018	0.154[a]	$0.095 < P < 0.213$
Semi-open riparian	8	0.006	0.035	$0.005 < P < 0.065$
Closed riparian	18	0.012	0.079[a]	$0.035 < P < 0.123$
Muhly riparian	16	0.023	0.070[b]	$0.029 < P < 0.111$
Open upland	4	0.013	0.018	$0 < P < 0.040$
Mixed upland	129	0.853	0.566[b]	$0.468 < P < 0.646$
Broadleaf upland	18	0.058	0.079	$0.035 < P < 0.123$
Total riparian	77	0.069	0.338[a]	$0.277 < P < 0.399$
Total upland	151	0.924	0.663[b]	$0.602 < P < 0.724$

Table 3. (continued)—Bonferrioni simultaneous confidence intervals for vegetation and habitat types. Based on observations during grazing periods (those periods in which 50% or more of the individuals were grazing).

Pasture/Collection Vegetation type	n	Expected usage	Actual usage	Bonferroni intervals for actual usage
Middle collection				
Open riparian	29	0.028	0.163 [a]	$0.095 < P < 0.231$
Semi-open riparian	4	0.006	0.023	$0 < P < 0.050$
Closed riparian	11	0.012	0.062 [a]	$0.018 < P < 0.106$
Muhly riparian	8	0.023	0.045	$0.007 < P < 0.083$
Open upland	5	0.013	0.028	$0 < P < 0.058$
Mixed upland	108	0.853	0.607 [b]	$0.517 < P < 0.697$
Broadleaf upland	13	0.058	0.073	$0.025 < P < 0.121$
Total riparian	52	0.069	0.293 [a]	$0.226 < P < 0.360$
Total upland	126	0.924	0.708 [b]	$0.641 < P < 0.775$
Late collection				
Open riparian	2	0.028	0.017	$0 < P < 0.046$
Semi-open riparian	3	0.006	0.025	$0 < P < 0.060$
Closed riparian	7	0.012	0.059	$0.006 < P < 0.106$
Muhly riparian		0.023		
Open upland		0.013		
Mixed upland	102	0.853	0.857	$0.778 < P < 0.936$
Broadleaf upland	5	0.058	0.042	$0 < P < 0.087$
Total riparian	12	0.069	0.101	$0.047 < P < 0.155$
Total upland	107	0.924	0.899	$0.845 < P < 0.953$

[a] Actual usage is greater than expected usage at the 0.10 level of significance.

[b] Actual usage is less than expected usage at the 0.10 level of significance.

there was very little forage available, it can be assumed they were making use of it for some other reason. Shading up during afternoon hours appears to be the most logical explanation. Mean maximum temperatures for July and August averaged 2° C warmer during 1985 than during 1984. This temperature difference may have been critical in influencing animals to make use of the closed-riparian type. Observations of cattle in the closed-riparian type also were greater than expected during October 1984. The reason for increased use during the fall period is not apparent.

Although it made up a very small proportion of the riparian habitat, seedling riparian was separated as a distinct vegetation type because of the negative concerns of grazing on cottonwood *Populus* spp. and willow *Salix* spp. seedlings (Carothers 1977; Glinski 1977). No preference was shown by cows for this vegetation type. Three of the more probable reasons are the light stocking rate, good conditions of other forage, and the scattered pockets in which seedling riparian occurred.

Increased observations in riparian vegetation zones during summer months was generally at the expense of observations in the mixed-upland type. Overall, observations occurring in the mixed upland type outweighed those occurring in all other zones. The mixed upland type, therefore, functioned as the reservoir of use with animals moving through the zone depending on the relative selection of other vegetation types.

Observations in upland habitat were never greater than expected, but when broken into vegetation types within uplands, use of many of the types was greater than expected. Observations in open-upland type were greater than expected during August 1984 and January, February, and May 1985. Rainfall was high during the summer of 1984, resulting in good production of blue grama *Bouteloua gracilis*, the primary grass in the open-upland vegetation type. This is probably the reason the open-upland was selected in August 1984. Selection for open upland during January and February of 1985 is more difficult to explain since open upland forage was dormant during this time. It seems unlikely as browse species were available close by, that open upland was selected for forage. Animal selection for the type may have been a result of calving. During the first few weeks following calving, cows chose to graze open areas so they could easily remain within sight of their calves. Use of open upland during May 1985 may have been a result of production of spring annuals or an early greening of blue grama. During February 1985, use on the browse-upland type was greater than expected. At this time the herbaceous vegetation was dormant and animals were observed making use of browse species.

There was individual selection for habitat types since cows tended to break into several smaller groups. Roath and Krueger (1982b) reported evidence of socially structured discrete groups of cattle on mountainous terrain. Arnold and Dudzinski (1978) reported that animals broke into smaller groups ranging from four to eleven animals. During this study the herd of approximately forty animals would break into three to four groups that would graze different areas of the pasture. Individual selections for habitat type were very similar. The similarity may result from the fact that cows graze in groups of 10-30, but the composition of the groups continually changes (Dwyer 1961). These smaller groups tended to graze in different parts of the pasture, consequently different habitat types. All collections were pooled and the proportion of observations within habitat types for individuals was compared. Selection by individuals was similar. The percentage of observations occurring in riparian habitats for individuals ranged from 9 to 15% with a mean of 12%. Upland observations for individuals were the mirror image of riparian observations with a range from 85 to 91% and a mean of 88%. These percentages were based on 3,400 observations.

A daily routine became apparent. Around dawn, cows became active, arising from their bedding areas on wooded ridges. Seventy-seven percent of all observations occurring at 0600 hours were in mixed-upland vegetation that occurred on ridges. They started grazing almost immediately. During this intense grazing period, cows grazed in mixed-upland or an adjacent vegetation type. As mid-day approached, grazing became erratic and intermixed with quiescent periods. By evening, cows had moved into the vegetation types preferred for grazing. Vegetation type selected depended on season. No matter what vegetation type was grazed during the evening grazing period, cows invariably moved to wooded ridges to bed down for the night.

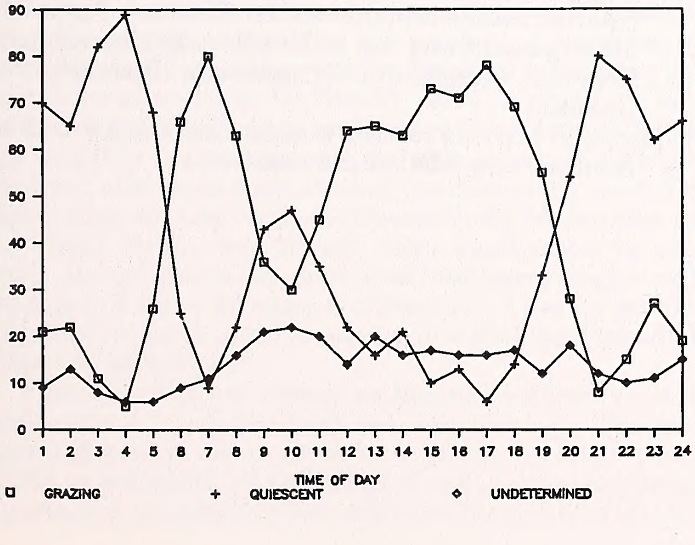
Apparently, wooded ridges offered the best bedding for animals. It was evident that the morning grazing started near the bedding area. Cattle are not influenced by a desire to eat quickly during the evening grazing period therefore, they tend to be more selective about where and when they forage (Arnold and Dudzinski 1978). In this study, observations in preferred vegetation types tended to be highest during the evening grazing period. As a result, during the summer when riparian habitats were selected, most such use occurred in the evening. Gillen et al. (1985) noted that riparian meadows were used more during the afternoon. Behavior and distribution in the early afternoon were varied. Grazing took place but was lethargic and intermixed with travel and quiescence. Locations of animals within vegetation types were inconsistent because of the varied behavior.

Daily and Seasonal Behavior

Behavior was separated into two primary categories, grazing and quiescence. Behavior was separated into only two primary categories for two reasons. Grazing and quiescence were believed the most important activities related to habitat use. They also were the easiest to delineate from the recordings. Observations in the undetermined categories were minimal and did not show any distinct pattern. Other investigators have cautioned about trying to interpret too much from recordings (Gillingham and Bunnell 1985).

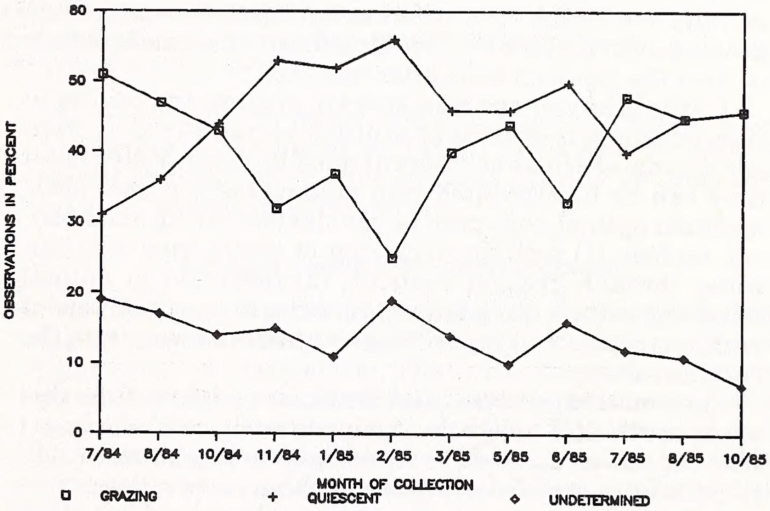
An overall daily behavior pattern was apparent (Figure 2). There were two grazing periods during the day. The short, but intense, morning grazing period occurred between 0600 and 0900 hours. The evening grazing period occurred between 1200 and 2000 hours. Grazing at the start of the evening period was lethargic, but increased in intensity. Quiescent periods occurred between grazing times.

Figure 2.—Mean daily behavior pattern of cattle.



Overall, behavior varied with season (Figure 3). Time spent in grazing daylight hours was highest during summer months (June through October), with a peak during July. Time spent grazing was lowest during winter days from November through February, with a low point in February.

Figure 3.—Mean seasonal grazing pattern of cattle.



The overall daily pattern of grazing and quiescence was similar to patterns reported by other authors (Squires 1981; Roath and Krueger 1982b; Marlow and Pogacnik 1986). There were small differences in daily patterns between years and seasons. These were influenced by changes in temperature, humidity, rainfall, and other factors. The grazing pattern during the early growing season was less intense, and spread over a longer period of time, when compared to other seasons. This was probably a result of selective grazing on spring annuals. Since animals obtained only a small amount per bite, they had to cover more ground to fill their rumens. This assumption is supported by data on daily distance traveled, which was highest during the early growing season (Goodman 1987).

During the dormant season, animals did not leave cover for long to graze. They had shorter foraging trips than at other times of the year. This is reflected in daily distance traveled which was lowest during this season. They also spent more time grazing during midday and took advantage of warmer midday temperatures.

Summary and Management Implications

Range management as a practice has two primary goals, to maximize animal production and to maintain or enhance productivity of forage species. This is difficult to realize considering the many factors that can influence these goals. It is generally conceded that riparian areas in the Southwest are in poor condition and that such conditions are often the result of improper livestock grazing. Riparian areas are productive in comparison to adjacent upland areas. Riparian areas certainly produce enough forage to allow moderate utilization. Grazing within riparian areas may be of primary concern during summer months because cattle tend to congregate more frequently in the riparian zone during these months (Severson and

Boldt 1978). Our results would support the possibility of concern toward summer grazing in riparian zones.

Stocking rates in the current study were light to moderate. Utilization was estimated to average about 20% on upland sites. Utilization of riparian areas was heavier, but never exceeded 45%. Because of its inherent productivity and the light stocking rate, riparian vegetation did not appear to be adversely affected. No utilization was observed on any woody vegetation. The acceptable level of utilization for forage species within riparian zones is not known. Cattle selection for riparian habitat was highest in July to September. Within riparian subtypes, greatest activity was in the open riparian during the evening. This grazing activity followed bedding down of animals within or near the riparian zone after midday.

Cattle behavior and time spent in grazing and resting in riparian zones is important to utilizing riparian area. Periods during which impacts occur must be recognized so that they can be incorporated into management plans. Management options that may be considered during such periods include (1) periodic exclusion of cattle from riparian zones through grazing systems, (2) reduction in animal numbers within the pasture, (3) reduction of time spent within a pasture, or (4) drifting of animals away from the riparian area.

Information gathered and conclusions drawn from this study are limited to lightly and moderately-stocked ranges with minimal riparian area within each pasture. Additional study is needed at higher stocking rates to determine if use in riparian areas is proportional to upland use. With heavier stocking rates, a better evaluation of the impact of cattle resting in riparian areas could also be determined. Ideally similar pastures with greater amounts of riparian habitat need to be evaluated during summer grazing to determine effects of amount of riparian zone on the degree of use it receives. Finally, the accepted level of utilization for riparian zones needs to be established.

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Compatibility of Livestock Grazing Strategies with Fisheries

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Abstract.—Livestock grazing strategies and techniques have been developed for upland ranges to increase plant and litter cover, encourage growth of favorable plant species, improve plant species composition, increase plant vigor, and protect soil from erosion. These same objectives must be met when using the riparian area for livestock grazing. Grazing strategies have been preliminarily evaluated here with respect to their compatibility with the requirements of the stream-riparian zone and a productive fisheries. A better understanding of management strategies with respect to their stream-riparian compatibility should help fishery specialists work more closely and effectively with range conservationists in rangeland management.

Livestock grazing strategies and related techniques have been developed to increase forage production, increase plant and litter cover, encourage growth of desirable forage plants, improve range condition, improve plant species composition, decrease soil erosion, and increase plant vigor on grazed lands (Holcheck 1983). Although these strategies should also benefit the fisheries in streams that flow through grazed lands, more information is needed to determine if the objectives are actually being met in stream-riparian systems (the complete stream and its surrounding riparian habitat) and whether they benefit fishery resources (the "fishery" refers to the fish and their complete habitat). Literature that reports evaluations of the compatibility of different grazing strategies with fishery resources is lacking (Meehan and Platts 1978).

Holcheck (1983) reported that, although grazing strategies have been a major focus of range research and management, range specialists still lack specific knowledge of the conditions under which individual grazing strategies give best results. This observation also applies to the status of fisheries research and management. Holcheck (1983) also found little difference in cattle performance (e.g., weight gains) and diet quality between the different grazing strategies (e.g., season-long continuous versus rest rotation). With little clearcut advantage from specialized grazing strategies on upland rangeland sites, there is little economic incentive for managers and users to change from one strategy to another. Therefore, economic benefits from grazing strategies designed to improve stream-riparian zones as well as fisheries must be demonstrated.

This report reviews the ability of current grazing strategies to meet fisheries needs based on the information in the references cited and on personal observation. The evaluation draws heavily on the experiences of the author. Also, the grazing strategies are evaluated based on the commonly used stocking rates and grazing intensities used on today's allotments. Obviously, one cow grazing a large allotment at 1% utilization under any selected grazing strategy would be compatible with fisheries needs. This report, however, evaluates each strategy as commonly used. This report concentrates on the northern Rocky Mountains and the Great Basin, but should have application in other areas. Range specialists and land managers might evaluate some of these strategies differently; I see no problem with this but present this report as a beginning that will be subject to refinement.

Fishery needs are viewed as the major objective in the evaluation of each livestock grazing strategy. The management goal is assumed to be that any strategy should attain or maintain all the affected range types (especially riparian) in a condition that will meet the needs of all other beneficial uses. However, the allocation of resources for combining the needs of all the different uses sometimes means that full productive capacity for any one resource may not always be achieved.

Grazing Strategy Development

Gifford and Hawkins (1976) showed that current grazing strategies failed to significantly increase plant and litter cover on watersheds. They also stated that grazing strategies appear to benefit only certain plant species. It is possible, then, that one plant species will increase in density while another will decrease. The net result may well be no change in watershed protection. Gifford and Hawkins' (1976) findings have application in stream-riparian management. Plant density and species composition changes have affected many stream-riparian systems in the western USA. A prime example is the historic reduction in stream canopy overstory along many western streams (Platts and Nelson, in press).

Historically, range managers have not distinguished between the different plant community types on the uplands from those of riparian ecosystems and have typically subjected both groups to the same grazing management strategy. This management approach is still commonly used and has caused serious fisheries problems because of the disproportionately heavy use of stream-riparian zones by livestock. Rangeland researchers and managers have had difficulty developing grazing strategies that counter the unbalanced animal distribution patterns that develop when livestock concentrate in stream-riparian zones. Holcheck (1983) noted that for any grazing strategy to work it must be tailored to fit the needs of the vegetation, terrain, class or kind of livestock, and the particular ranching operation involved. Today's range and fisheries specialists must tailor grazing to fit the needs of streambanks, stream channels, water quality, and streamside vegetation. If the riparian area is the key to productive fisheries, then the grazing strategy must meet the needs of the key vegetation species, whether they be ungrazable brushy species or palatable grasses.

Specialists have progressed slowly in evaluating grazing strategies with respect to fisheries' needs, and our understanding interrelationship is so far rudimentary. Information and sound conclusions require time to attain, but managers must make decisions daily using the best information available. They do not have the luxury of waiting years for research to find a definitive solution. This report evaluates commonly used grazing strategies based on present limited data.

Options for Strategy Development

Seven major options are available when developing grazing strategies that incorporate fisheries compatibility. To be successful, combinations of the following options are usually required:

(1) control of grazing frequency (includes complete rest);
(2) control of livestock stocking rates;
(3) control of livestock distribution;
(4) control of the timing (season) of forage use;
(5) control of livestock kind and class;
(6) control of forage utilization;
(7) artificial rehabilitation rangeland fisheries.

Controlling animal stocking rates has been the principal option used, but controlling numbers alone has had only limited success on stream-riparian zones. Rest is built into strategies such as rest-rotation to improve plant condition, and deferred strategies use the timing of forage use to enhance plant vigor and seeding success. The control of the the kind and class of livestock can be highly successful but is seldom used. The artificial rehabilitation of rangeland fisheries should be a last-resort option. Natural rehabilitation under proper stewardship should receive first consideration.

Evaluation of Selected Grazing Strategies and Techniques

Each grazing strategy or technique is evaluated with respect to how its use relates to potential impacts on fishery productivity (Table 1). The range profession does not list or define some of the strategies used in this report; what they do define, they call systems. Problems, benefits, and fishery compatibility are outlined and rated for each grazing strategy (Table 2). Ratings range from 1 to 10, with 1 indicating little or no fishery compatibility and 10 representing complete compatibility with fishery needs. Grazing strategies are evaluated based on their effect on amount of streambank vegetation used, control of animal distribution, effects on streambank stability, ability to maintain brushy species, control of seasonal plant regrowth, and the ability of a stream-riparian habitat to rehabilitate while under the influence of the strategy.

The descriptions of the more commonly used grazing strategies are derived from the works of Kothmann (1974), Gifford and Hawkins (1976), and Holcheck (1983). The definitions used by Kothmann (1974) are used in this report whenever possible. These researchers' work was also used to identify certain problems and benefits. Interpretations on corridor fencing, riparian pasture, rest, rest rotation, double rest rotation, and seasonal preference as related to fisheries needs were taken from Platts (1981, 1984), Platts et al. (1983, 1985), Platts and Wagstaff (1984), and Platts and Nelson (1985a, 1985b, 1985c, 1985d). The grazing strategies were rated (Table 2) using information available in the previous citations and unquantified experiences of the author. This rating guide will need to be reviewed and refined over time, but for now it is something for specialists to work with.

Grazing strategy definitions listed by Kothmann (1974) are used in this report. Kothmann does not define many of the commonly used strategies, so definitions from Holcheck (1983) and Gifford and Hawkins (1976) were used whenever possible. However, any definition will be changed to meet a new definition that appears in updated versions of the range term glossary or the "Glossary of Aquatic Terms" published by the Western Division of the American Fisheries Society.

Table 1.—Potential effects of grazing on aquatic and riparian habitats that should be considered when grazing strategies or grazing related techniques are evaluated.

Stream banks

(1) Shear or sloughing of stream-bank soils by hoof or head action.
(2) Water, ice, and wind erosion of exposed stream-bank and channel soils because of loss of vegetative cover.
(3) Elimination or loss of stream-bank vegetation.
(4) Reduction of the quality and quantity of stream-bank undercuts.
(5) Increasing stream-bank angle (laying back of stream banks), which increases water width and decreases stream depth.

Water Column

(1) Withdrawal of streamflow to irrigate grazing lands.
(2) Drainage of wet meadows or lowering of the groundwater table to facilitate grazing access.
(3) Pollutants (e.g., sediments) in return water from grazed pasture lands, which are detrimental to the fisheries.
(4) Changes in magnitude and timing of organic and inorganic energy (i.e., solar radiation, debris, nutrients) inputs to the stream.
(5) Increases in fecal contamination.
(6) Changes in water column morphology, such as increases in stream width and decreases in stream depth, including reduction of streamshore water depth.
(7) Changes in timing and magnitude of streamflow events from changes in watershed vegetative cover.
(8) Increases in stream temperature.

Channel

(1) Changes in channel morphology.
(2) Altered sediment transport processes.

Riparian Vegetation

(1) Changes in plant species composition (e.g., brush to grass to forbs).
(2) Reduction of floodplain and stream-bank vegetation, including vegetation hanging over or entering into the water column.
(3) Decrease in plant vigor.
(4) Changes in timing and amounts of organic energy leaving the riparian zone.
(5) Elimination of riparian plant communities (i.e., lowering of the water table allowing zeric plants to replace riparian plants).

Continuous Season-Long (Cattle)

Continuous season-long grazing (cattle) for this report is grazing a particular pasture annually throughout the complete vegetation growing season. Kothmann (1974) defines continuous grazing as grazing of a specific unit throughout a year or for that part of a year during which grazing is feasible. Under the continuous season-long strategy, livestock congregate and linger on riparian streambank areas because of the presence of succulent forage,

Table 2.—Evaluation and rating of grazing strategies based on the author's personal observations, as related to stream-riparian habitats.

Strategy	Level to which riparian vegetation is commonly used	Control of animal distribution (allotment)	Stream-bank stability	Brushy species condition	Seasonal plant regrowth	Stream-riparian rehabilitative potential	Rating
Continuous season-long (cattle)	Heavy	Poor	Poor	Poor	Poor	Poor	1[a]
Holding (sheep or cattle)	Heavy	Excellent	Poor	Poor	Fair	Poor	1
Short duration-high intensity (cattle)	Heavy	Excellent	Poor	Poor	Poor	Poor	1
Three herd — four pasture (cattle)	Heavy to moderate	Good	Poor	Poor	Poor	Poor	2
Holistic (cattle or sheep)	Heavy to light	Good	Poor to good	Poor	Good	Poor to excellent	2-9
Deferred (cattle)	Moderate to heavy	Fair	Poor	Poor	Fair	Fair	3
Seasonal suitability (cattle)	Heavy	Good	Poor	Poor	Fair	Fair	3
Deferred-rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Stuttered deferred-rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Winter (sheep or cattle)	Moderate to heavy	Fair	Good	Fair	Fair to good	Good	5
Rest-rotation (cattle)	Heavy to moderate	Good	Fair to good	Fair	Fair to good	Fair	5
Double rest-rotation (cattle)	Moderate	Good	Good	Fair	Good	Good	6
Seasonal riparian preference (cattle or sheep)	Moderate to light	Good	Good	Good	Fair	Fair	6
Riparian pasture (cattle or sheep)	As prescribed	Good	Good	Good	Good	Good	8
Corridor fencing (cattle or sheep)	None	Excellent	Good to excellent	Excellent	Good to excellent	Excellent	9
Rest rotation with seasonal preference (sheep)	Light	Good	Good to excellent	Good to excellent	Good	Excellent	9
Rest or closure (cattle or sheep)	None	Excellent	Excellent	Excellent	Excellent	Excellent	10

[a]Rating scale based on 1 (poorly compatible) to 10 (highly compatible with fishery needs).

drinking water, gentle terrain, shade, and vegetation. These areas usually receive excessive use even under light stocking rates (Platts and Nelson 1985c). Operating costs are minimal because fencing is minimal and stress to livestock due to gathering, trailing, and changing pastures is reduced. This grazing strategy is seldom compatible under commonly used forage intensity and seasons of use because too much pressure is exerted on riparian plants and streambanks (Platts et al. 1983, 1985; Platts and Nelson 1985b).

Holding (Sheep or Cattle)

The holding strategy, as used in this report, calls for holding grazing animals for long periods or under heavy stocking rates on a selected area. It differs from the closed herding definition used by Kothmann (1974), which relates primarily to the spread of a herd while grazing and the handling of a herd in a closely bunched manner to restrict the natural spread of the animals when grazing. The holding strategy is different because it is more contained and often used during waiting periods until conditions become right to move animals to other areas. Examples include holding on private pastures, use of U. S. Forest Service administrative pastures, holding on lower elevation meadows until higher elevation areas are ready for grazing or breeding pastures, and holding on areas until transportation to another area can be arranged. This strategy is usually not compatible with fisheries because season and proper use receive little consideration. When sheep are forced to concentrate (i.e., are held) on stream-riparian areas, they adversely affect these environments in much the same way as cattle (Platts 1981).

Short Duration-High Intensity (Cattle)

This strategy calls for rotating high intensity use over short periods. Kothmann (1974) defines this as any system of grazing management that uses a stocking density index greater than two. The stocking density index is the reciprocal of the fraction: land available to the animals at any one time divided by the land available to the animals for the entire grazing period. This strategy is sometimes called rapid rotation grazing (Steger 1982). It is sometimes used in a wagon-wheel arrangement with several pastures radiating outward, like the spokes of a wheel, and served by a central water supply. Regardless of the design, each paddock or pasture is given a short period of intensive grazing under high animal stocking rates followed by a longer period of rest for recovery.

To be successful, this strategy often requires ranges that receive adequate season-long precipitation or irrigation for plant regrowth. The grazing use probably places too much grazing and mechanical pressure on brushy species and streambanks. The initial expense (mainly fencing) to develop the pastures is high.

The strategy does result in better animal distribution, which results in more even pasture use, and it has been successfully applied on flat upland grassland types (Steger 1982). Stocking rates can often be substantially increased in comparison to corresponding rates under continuous season-long grazing. This short duration-high intensity strategy places livestock in the riparian stream habitat over intervals spanning the entire grazing season.

Three Herd-Four Pasture (Cattle)

This strategy closely resembles deferred rotation. It calls for grazing each pasture continuously for a year, and then each pasture is given 4-months of nonuse. With four pastures, nonuse can be staggered so that it occurs in each pasture during each period of the year by the end of the 4-year cycle. Livestock are allowed to graze the streambank forage over all periods of the year. Thus, early grazing can cause streambank shear and late grazing can eliminate vegetation needed to buffer high stream flows and ice erosion.

Better plant production has been obtained with this strategy on uplands where adequate precipitation occurs during the entire year. However, constant grazing pressure on brushy plant species occurs during the year of continuous grazing. The 4 months of rest allows some rehabilitation, but only one rest period every 4 years may be insufficient for fishery needs.

Holistic (Cattle or Sheep)

This strategy, often referred to as the Savory grazing method (Savory and Parsons 1980), is difficult to define because it is largely in the mind of the beholder. The strategy is usually thought of as heavy stocking and frequent movement of animals dependent upon the growth cycle of the plants. The strategy is similar to short duration-high intensity; the major difference is that the holistic grazing method must include daily planning and flexibility to obtain the desired animal performance through the dimensions of time, number, and space (Steger 1982). The timing of grazing and rest is supposedly keyed to plant and soil environmental conditions and needs. Neither the holistic nor the short duration-high intensity strategies have been adequately tested on stream-riparian zones to draw many conclusions. Supposedly, the hoof action and mechanical disturbance of soils will improve infiltration, decrease overland flow, and promote better riparian zones by reducing peak stream flows. But there is no proof that this is true for riparian areas.

One excellent feature of the holistic strategy is that the livestock operator is forced to think about management options and possible responses and to provide daily supervision. Most grazing techniques do not require this degree of sophistication. However, the operator will still have difficulty determining needed forage use, forage timing, and animal movements because these have to be keyed to imprecisely defined environmental conditions requiring intensive training and more of the operator's time than is usually available. Livestock hooves can churn the soil, break the surface soil capping, trample ground litter, disturb soils for increased soil porosity, and encourage seedling establishment. Such conditions do not necessarily meet the needs of maintaining streambank stability, streambank morphology, channel form, and brushy vegetation.

Although this strategy has been credited for improvement of some upland range types (Savory and Parsons 1980), there is insufficient information to determine if this is true. Most allotments on public lands are too small and homogeneous to provide the options needed to make this method work. Success has been gained on some large ranches where needed options are available.

Deferred (Cattle)

This strategy delays pasture grazing until the more important forage plants develop seed or attain desired regrowth. Kothmann (1974) defines this strategy as the use of deferment in grazing of a management unit, but not in a systematic rotation including other units. This strategy calls for the discontinuance of grazing on various parts of a range in succeeding years, allowing each part to rest successively during the growing season to permit seed production, establishment of seedlings, or restoration of plant vigor. The strategy requires more fencing and cattle movement than the continuous season-long strategy. The deferred late grazing period and higher animal stocking rates may remove vegetation needed to protect streambanks from future ice and water scouring. Early grazing may increase streambank shear.

The periods of nonuse do provide opportunities to improve plant vigor and cover for the preferred grazing plants, and more even animal distribution occurs over the complete pasture than in season-long grazing. This strategy can be especially effective where considerable differences would normally exist between the consumption of different plant species and accessibility of plants to be grazed. The deferment adds periods of nonuse that can improve the capability of the vegetation to protect streambanks from erosion. To be successful, a sufficient amount of herbage needs to remain at the end of each grazing treatment, especially at the end of the late grazing period, for fisheries needs.

Seasonal Suitability (Cattle)

This strategy restricts the use of vegetation to a specific season (Kothmann 1974). The range or allotment is partitioned into pastures based on vegetation types, plant condition classes, or accessibility conditions. The best pasture, from a livestock nutritional standpoint, is selected for use for each season of the year. This strategy has application in those rangelands having high elevation differences or different randomly distributed precipitation patterns. The strategy is sometimes called the "best pasture system."

Higher fencing cost and increasing need to move animals from pasture to pasture to fit seasons of use raises costs. Also, the riparian habitat could be selected as the "best pasture" and therefore could receive levels of use detrimental to fisheries habitat. This strategy does not account for the need to decrease streambank erosion and protect brushy species, and the "best pasture" selection may require higher animal stocking rates per unit area at critical plant growing periods or periods when streambanks are most susceptible to shear.

Selected nonuse periods could allow degraded streambanks and riparian vegetation some time to recover from past damage, but because each pasture may be grazed every year, this programmed nonuse may not be adequate. Riparian areas, because of their nutritional content, would probably receive heavy grazing under this strategy, and fisheries habitats would therefore decline.

Deferred-Rotation (Cattle)

Rotation is an orderly sequence of use when some or all subdivisions (pastures) are both grazed and deferred during the same grazing season or calendar year. Kothmann (1974) defines deferred-rotation grazing as any strategy having a stocking density index greater than one but less than two, which provides for a systematic rotation of the deferment among pastures. Steger (1982) states that under deferred-rotation strategies, half or more of the land in the system (strategy) is being grazed at any given time, and the time a pasture is grazed equals or exceeds the period of rest. In this strategy, at least one pasture is deferred during part of the grazing season, and this deferment is then rotated among pastures (a minimum of two and frequently four pastures) in succeeding years. This strategy is commonly used to graze one pasture during the early part of the grazing season and then graze the remaining pastures during the late part. The following year the pasture use sequence is altered so the early grazed pasture last year is deferred to late grazing this year.

This strategy requires additional fencing and cattle movement. It calls for alternate year (under the two-pasture design) early livestock grazing when streambanks may be susceptible to shear damage, and for every other year late when plant regrowth may be needed to protect streambanks from ice and flood scour. In some cases the livestock manager can have the option of controlling use levels on critical areas. Because of the deferment, vegetation has the opportunity to store carbohydrates and set seed every other year. The strategy provides some control of animal distribution.

This strategy does provide some nonuse during some critical streamflow and plant growth periods and thus may increase streambank plant cover. Over 2 to 4 years, however, each pasture is grazed over the complete grazing season providing the possibility of streambank shear and vegetational mat elimination.

Stuttered Deferred-Rotation (Cattle)

This strategy is similar to deferred-rotation in that one pasture is deferred for part of the plant growth period; this deferment period is rotated among pastures in succeeding years. Under a two-pasture design, the deferred-rotation strategy grazes one pasture early one year and another pasture late, and then the pattern is reversed the following year. In the stutter, the sequence calls for use of one pasture early the first 2 years, and use of the other pasture late the following 2 years, taking 4 years to complete the cycle.

Fisheries compatibility is similar to deferred-rotation except that the two successive years of early grazing on one pasture and late grazing on the other pasture may give brushy species some relief. Because of the deferment, vegetation has the opportunity to store carbohydrates and set seed every other year. The strategy provides some control of animal distribution.

This strategy does provide some nonuse during some critical streamflow and plant growth periods and thus may increase streambank plant cover. Over 2 to 4 years, however, each pasture is grazed over the complete grazing season providing the possibility of streambank shear and vegetational mat elimination.

Winter (Sheep or Cattle)

Winter grazing is a form of seasonal grazing. Grazing occurs only during winter conditions, and to be successful, streambanks should be frozen and all riparian plants must be dormant. Rangelands must receive only light snowfall to allow livestock access to the forage. Heavy grazing can eliminate the streambank vegetational mat needed to prevent soil erosion due to winter-spring floods or ice events and to transfer grazing from grasses to shrubby species, unless controlled.

Winter grazing can eliminate or reduce supplemental winter feeding. Frozen streambanks are more resilient to mechanical damage minimizing streambank shear. Carbohydrates have returned to the root system, prior to the grazing season, providing the opportunity to increase plant vigor.

Rest-Rotation (Cattle) - Commonly Three or Four Pasture

The rest-rotation strategy calls for a multipasture design where each pasture receives at least 1 year of complete rest during each grazing cycle. This is an intensive system of management calling for extensive fencing and animal movement whereby grazing is deferred on various parts of the range during succeeding years, allowing the deferred part complete rest for 1 year. Two or more management units are required. Kothmann (1974) defines rotation grazing as a strategy of pasture use embracing short periods of heavy stocking followed by periods of rest for herbage recovery during the same season. It is generally used on tame or cropland pasture. Kothmann does not define rest-rotation.

The fishery habitat rehabilitation gained from the rested year may be nullified by the higher use that occurs on each of the grazed pastures. Also, during each grazing cycle, livestock will have grazed the streambanks during all seasons of use. In 1 year out of each 3-year grazing cycle, assuming a three-pasture design (but it could be any number), the streambank vegetation is grazed late and the cover necessary to buffer erosion from floods and ice is reduced. In 1 year out of each 3-year grazing cycle, streambanks are grazed when soil moisture is high (usually in spring or early summer), and shear damage can result (Platts and Nelson 1985a).

The year of rest (assuming a three-pasture strategy) gives plants and streambanks the opportunity to rehabilitate from past damage. In 2 years out of the 3-year grazing cycle, the vegetation is left on the streambanks to help buffer any water and ice erosion. In 2 years out of each 3-year grazing cycle, livestock are not grazing streambanks during the early grazing periods when shear potential may be high. Streams that have a high natural rehabilitative rate can recover during the rest period, but those streams that do not have this high potential may continue to degrade. This strategy appears successful on stream-riparian habitats where the channel is maintained and controlled by vegetation. This usually only applies to ephemeral channels.

Double Rest-Rotation (Cattle)

In this strategy, the pasture with the highest riparian and stream values receives twice the rest that would normally be applied during a commonly used rest-rotation grazing cycle. In a three-pasture design, the pasture with the highest stream-riparian values is rested continuously for 2 years and then grazed early or late the third year, then rested 2 years and grazed early or late the third year. Thus, it takes 6 years to complete the cycle.

Benefits usually exceed those from the commonly used three-pasture rest-rotation strategy because the stream-riparian habitat has 2 years in a row, instead of one, to rehabilitate from any applied stress. Brushy species have 2 successive years of twig growth before grazing occurs again.

Seasonal Riparian Preference (Cattle or Sheep)

This strategy, as defined for this report, requires that concerned riparian stream values are in pastures that can be grazed during the season that is most compatible with fishery needs. Kothmann (1974) defines seasonal grazing as grazing restricted to a specific season. Unless closely managed, streambanks can still receive shear stress and late season grazing can reduce the vegetation needed to minimize flood erosion; also, it is difficult to determine seasonal preference because seasonal climatic conditions vary from year to year. The strategy does allow livestock to graze streambanks during their most shear-resistant period and when brushy species would receive the least use. Managers must have a good data base or experience to be able to determine the preferred period of use.

Riparian Pasture (Cattle or Sheep)

This technique may be a separate strategy or be used as part of or in combination with another strategy. Similar to the seasonal riparian preference strategy, the riparian pasture places the selected stream-riparian habitat, or portions of this habitat, within one or more pastures (Platts and Nelson 1985d). Unlike the seasonal preference pasture that becomes a working pasture within the grazing cycle, the timing and use of forage within the riparian pasture is set strictly to meet previously determined riparian stream objectives. The pasture can be grazed or rested on any given season or year depending on stream-riparian needs.

This strategy usually requires even more fencing, maintenance, and livestock movement than rotational or deferred strategies. Without effective control of animal numbers and animal distribution, the riparian pasture can lead to unbalanced animal distribution and disproportional forage use in the remaining pastures during certain parts of the season.

This strategy allows forage use and timing to be set to match the productivity of the stream-riparian habitat while allowing a much simpler and more economical grazing strategy to be used in the surrounding upland pastures. As the riparian vegetation regains its vigor and productivity, available forage for livestock use can often be increased under this strategy.

Corridor Fencing (Cattle or Sheep)

In this technique, all the stream-riparian habitat, or required portions thereof, are fenced to try to obtain rest or the application of a desired grazing method.This strategy requires extensive fencing, which increases operating costs while usually eliminating livestock forage within the corridor. Corridor pastures are usually too small and narrow for proper grazing under a pasture concept. Corridor fencing allows onsite stream-riparian habitat to rehabilitate while allowing grazing targets to be met on the uplands using simpler grazing strategies.

Rest-Rotation with Seasonal Preference (Sheep)

This strategy is the same as that used with rest rotation grazing with cattle, except with sheep the herding allows riparian habitats to be grazed during periods and intensities of least impact. The livestock operator must move sheep into different pastures as determined by the rest-rotation requirements and, in turn, graze riparian zones at selected times. The rest period gives riparian plants and streambanks the opportunity to recover from past use (Platts 1981).

With good herding and compatible sheep stocking rates, this grazing strategy can meet the needs of both the riparian and upland habitats. Because sheep are grazers that usually prefer slopes and upland areas, they naturally tend to graze streambanks less than cattle do. This strategy can be successful and has been found to produce no significant adverse impacts to fishery habitats (Platts 1984).

Rest or Closure (Cattle or Sheep)

This strategy calls for complete rest (some areas may not be suitable for grazing), or the allotment or selected pastures therein are to be ungrazed until stream-riparian habitats improve to meet fisheries management objectives. Kothmann (1974) defines rest as a period of deferment included as part of a grazing system. Rest is usually thought of as a period of time equaling or exceeding one complete year of nonuse. Rest eliminates all forage use by livestock, so livestock producers could be impacted financially.

Complete rest usually allows riparian stream habitats to immediately move toward their potential productivity, with fisheries products increasing in value (Platts et al. 1983; Platts and Nelson 1985a). This allows degraded allotments, pastures, and stream-riparian habitats to regain the productivity needed so that they can then be placed under suitable grazing strategies.

Discussion

In the past, no commonly used livestock grazing strategy was capable of maintaining high levels of forage use while rehabilitating damaged streams and riparian zones (Meehan and Platts 1978; Platts 1981). The main reason for this was the fact that range management practices combined different vegetative habitats, including the riparian, into one management unit. Another reason was the natural attraction of livestock, especially cattle, to riparian zones. Presently, no grazing strategy exists that will function under all situations, but with present knowledge, some strategies can produce good results under the right conditions.

The most promising grazing strategies for maintaining or rehabilitating riparian-stream systems are those that include one or more of the following options:

(1) including a riparian pasture within a grazing allotment or operation to allow riverine-riparian ecosystem to be managed separately from the uplands;

(2) fencing streamside corridors to allow stream-riparian habitats to rehabilitate;

(3) changing the kind of livestock (from cattle to sheep on certain ranges) for better grazing compatibility with rangeland types;

(4) adding more rest to the grazing cycle;

(5) reducing intensity of use on streamside forage;

(6) controlling the timing (often season) of forage use so grazing occurs during periods most compatible with riverine riparian ecosystems;

(7) managing grazing programs as specified and required in properly prepared allotment management plans or other proven management guides, therefore giving full consideration to riparian management objectives.

In reference to item 1, in our seven small experimental riparian pastures where cattle numbers were controlled to achieve desired forage use of the riparian vegetation, the utilization of upland forage normally exceeded that of the streamside forage by an average of about 13% — just the opposite of the typical allotment pasture (Platts and Nelson 1985c). Because they are usually drawn to moist sites, cattle will often override the grazing strategy if pasture size is too large for animal control. Also, no grazing strategy is going to work for stream fishery needs if there is not a set amount of vegetation left at the end of the growing season to buffer future ice and flood flows.

With item 2, range and fishery specialists have attempted to solve problems by fencing stream-riparian habitats. Standard cost for two 30-m corridors is about $3,750 (USA) per stream kilometer, with $38 to $125 maintenance costs per stream kilometer per year. About five animal unit months of forage are lost per stream kilometer fenced (Platts and Wagstaff 1984). Fencing streamside corridors is a last resort, but it may allow those grazing strategies that are working well in the uplands, but not in the riparian zone, to be compatible over the watershed as a whole.

In item 3, there is opportunity, especially in the higher elevation areas, to change the grazer from cattle to sheep on those allotments where sheep grazing is more compatible. In two Frenchman Creek study sites, which have been grazed by sheep under a programmed three-pasture rest rotation strategy since 1967, I can find no incompatibility of this strategy with fishery needs (Platts 1984). Proper herding, forage use, and timing of forage use can make this strategy completely compatible with fishery needs.

Item 4 calls for adding more rest to the grazing cycle. Holcheck (1983) has stated that the benefits from rest in one pasture may be nullified by the extra use that occurs on the remaining grazed pastures. Our studies (Platts and Nelson 1985a, 1985c) tend to support his statement when use of the riparian forage is heavy. However, a three-pasture rest rotation strategy can leave a vegetative mat on the streambank on 2 out of every 3 years, 1 year during early grazing and the other during the rested year. A double rest rotation grazing strategy (1 year grazing, 2 years rest) has been successfully used on high elevation pastures (Platts 1984).

Items 5 and 6 need much more study because the proper grazing of streamside vegetation requires tight control of animal distribution. In many areas it is not desirable or economically feasible to fence every streamside corridor to create corridors or riparian pastures (Platts and Wagstaff 1984). Therefore, grazing strategies that have better control over intensity and timing of forage use in riparian areas must be developed. Winter grazing, types of rest rotation strategies, and deferments that allow protective mats to be maintained on the streambank during critical runoff periods show promise, but again, more analysis is needed.

Item 7 calls for proper management of allotments, rangelands, or pastures, as required under the guidance plans. If grazed lands cannot be managed properly, as plans require, then no grazing strategy is going to work.

Fishery specialists, working closely with range specialists, must analyze each grazing plan with respect to its compatibility with fishery resources. Each plan must then be further evaluated to determine how well it meshes with basic and complete watershed needs. The stream and the watershed function as a unit. If the grazing management is not conducive to good watershed conditions, good stream conditions will also not exist.

Once they have deteriorated, many stream-riparian habitats are difficult to rehabilitate and need special management. In many situations, the stream-riparian habitat must be considered the key area for rangeland or pasture management. Livestock grazing under proper strategies with controlled intensities, timing, and animal distribution can permit grazing use of riparian stream ecosystems and foster acceptable results. This move toward better rangeland management could easily give society the highest rate of return for time and money expended.

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Response of a Southwest Montana Riparian System to Four Grazing Management Alternatives

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Abstract.—The effects of deferred rotation, time control (Savory Grazing Method), season-long, and livestock exclusion on streambank stability and trout habitat condition in a southwestern Montana riparian zone has been monitored since 1986. Although livestock exclusion appeared to improve channel conditions in 1986, there was no significant difference among any of the treatments thereafter. The decline in trout habitat condition appeared to be more a function of stream discharge and channel aggradation than grazing management. The lack of significant differences ($P < 0.10$) in bank stability among the various treatments during three consecutive drought years suggests that it is the interaction between grazing and stream discharge events that dictate the magnitude of streambank alteration. Downward shifts in livestock numbers will probably not limit streambank degradation and loss of trout habitat. Decreasing the length of time cattle have access to a stream reach and adjusting the grazing period to coincide with low streambank moisture levels shows promise for the improvement of riparian zone condition.

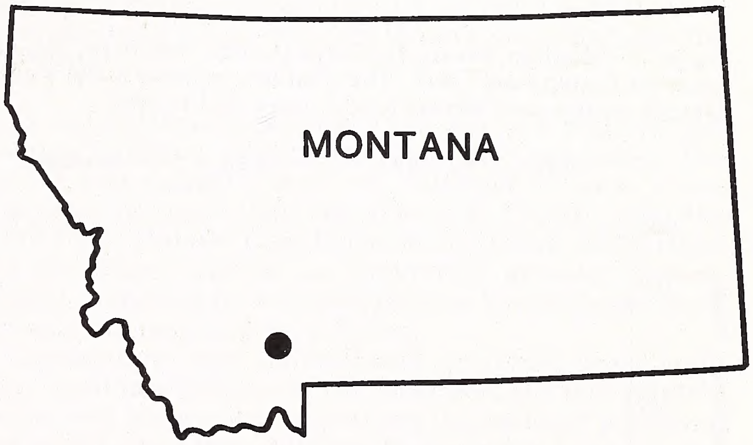
Wildlife and land managers seldom have to defend the importance of riparian ecosystems since the 1978 Callaway Gardens Symposium (Johnson and McCormick 1978). Now efforts are directed to finding the most effective management alternatives for rehabilitating or protecting local wetland, floodplain, and streamside communities. This is especially so in the semi-arid and arid regions of the western USA where livestock grazing on public lands is a common practice. Successful rehabilitation or protection of riparian communities on livestock grazing allotments is thought to be unlikely without first placing the allotment under a resource sensitive level of stocking and management intensity (Davis 1986). Resource sensitive stocking intensity may be interpreted as a reduction in livestock numbers. Although such a decision appears logical, a reduction in numbers does not eliminate the problem, it only restricts impact to smaller areas within the allotment pastures. Since the stream and its watershed function as a unit (Platts and Rinne 1985), those areas still being impacted will continue to limit the likelihood of riparian improvement along the stream course. This occurs because cuts in animal numbers do not mean an automatic modification in animal grazing behavior; individuals will still feed in preferred sites and forage primarily on preferred plant species. Resource sensitive stocking rates and management requires that livestock grazing behavior be sufficiently modified to limit negative impacts to the riparian community. In light of this need, we describe the response of certain riparian components to several grazing management methods that can be used to modify livestock grazing behavior.

Study Site

Site Description

We are studying a first order stream, Cottonwood Creek, on the Red Bluff Research Ranch near Norris, Montana (Figure 1). The stream was classified according to Rosgen (1985) (Table 1). Landform and vegetation are typical of lower elevational mountain slopes in southwestern Montana. Quaking aspen *Populus tremuloides*, Bebb's willow *Salix bebbiana*, and beaked sedge *Carex rostrata* dominate the riparian zone. A more detailed description of physiography and vegetation type is given in Marlow et al. (1987). Streambanks had less than 10% of their upper 1.0-m profile filled with rock or gravel. Bank soil texture was predominately a loamy sand.

Figure 1.—Location of Cottonwood Creek study site on the Montana Agricultural Experiment Station's Red Bluff Research Ranch in southwestern Montana.



Prior to the initiation of the present study, most of the area under investigation had been grazed under moderate stocking rates (measured utilization was 40-60%) at set periods of use (Marlow et al. 1987). Earlier, 1967 to 1980, the area had been grazed by 30-40 head of horses or 50-100 cow/calf pairs for approximately 90 d each year. From the late 1930s until 1967, when the Montana Agricultural Experiment Station bought the ranch, the Cottonwood drainage was intermittently grazed by 1,000 to 2,000 domestic sheep. The impact from sheep grazing on the drainage is difficult to determine because of nonexistent range condition data from the period of private ownership. However, by 1974, a Soil Conservation Service survey of the Red Bluff Research Ranch indicated that about 80% of the Cottonwood drainage was in good range condition. Unfortunately, the survey provided no information on the health or condition of the riparian areas.

Stream Discharge Conditions

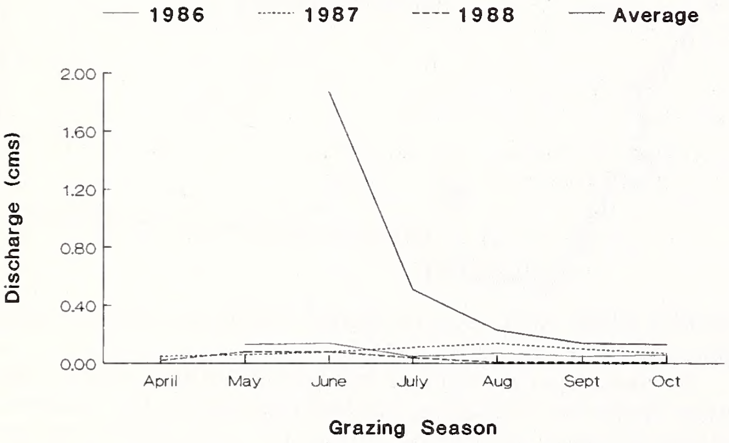
Since the initiation of this project in 1986, the study area has experienced below normal stream discharge during the period extending from May to August (Figure 2). According to U. S. Geological Survey water survey data, 1987 stream-

Table 1.—Characterization of Cottonwood Creek according to Rosgen (1985).

	Characteristics					
Type	Gradient	Sinuosity	Ratio	Particle size	Entrenchment	Landform
C^5	≤0.1	2.5+	5+	Silt/clay, medium to fine sands (little bed armour)	Moderate to slight confinement	Alluvial terraces with fine to medium textured soils. Predominately noncohesive materials.

flows in the portion of the Missouri River drainage occupied by the study site were 62% of normal (Shields et al. 1987). Not only was annual stream discharge down, but streamflow during the month of June 1987 was substantially lower than normal. The low flow was attributed to the less than normal snowpack and warmer than usual temperatures during 1986 and early 1987 (Shields et al. 1987). This pattern is critical to the results of this study because of the apparent close interaction between high flow events, cattle use, and streambank alteration (Marlow et al. 1987).

Figure 2.—Monthly stream discharge in cubic meters per second (cms) for Cottonwood Creek. The solid line represents the 4-year average for the same stream for the years 1981 to 1984.



Methods

Grazing Management Strategies

Realistically, managers can only control when livestock graze an area, how long they stay in the area, and how many individuals are present during the scheduled grazing period. Consequently, the grazing management methods used in this study represent several combinations of animal numbers, length of stay in a particular pasture, and the season of grazing.

Season-long.—Under this management strategy the manager attempts to control livestock impact by adjusting livestock numbers within a paddock. This is usually accomplished by calculating a stocking rate for the paddock or allotment in question. These rates, expressed as a cow/calf pair or animal unit per month (AUM), are based on the amount of forage in the paddock which can be utilized by livestock without impairing forage plant vigor. Following this approach, 127 cow/calf pairs were grazed in the Cottonwood Creek pasture for 90 d. This is equivalent to a 0.25 AUM/hectare stocking rate. To modify cattle behavior, salt was placed 0.75 km away from Cottonwood Creek to encourage cattle use of upland areas and to reduce the amount of time they spent in the riparian zone.

Deferred rotation.—This grazing strategy gives the manager more control over livestock behavior by adjusting the number of animals using the pasture and then scheduling grazing for periods when grazing induced changes can be minimized. For example, deferment of grazing until preferred forage plants have nearly matured improves the health and vigor of the vegetation, thereby improving overall range condition (Wamboldt 1974). In terms of riparian zone condition, grazing deferment was based on the moisture level of streambanks rather than plant phenology in an effort to limit or reduce bank alteration (Marlow et al. 1987). A further refinement of the traditional deferred rotation grazing method for use in this study was the movement of cattle from a paddock when 40 to 50% of the riparian forage base had been used. The level of forage utilization in the adjacent uplands was not considered in deciding when the cattle were to be moved. Consequently, cattle had access to the riparian areas of each paddock for a shorter length of time than the cattle grazing under season-long management.

Under deferred rotation, four cow/calf pairs grazed the designated deferred rotation paddocks on Cottonwood Creek for 14 to 28 d or at a stocking rate of 9 AUMs/hectare. Grazing began in a different paddock each year to achieve the necessary deferment until streambank moisture levels were low enough to limit trampling damage.

Time control (Savory Grazing Method).—This management strategy provides the most intense control of livestock behavior. By concentrating large numbers of livestock in relatively small paddocks, the manager has finally reached a point where the desired level of livestock use for certain areas or vegetation can actually be controlled. Plant vigor and soil surface conditions are protected by allowing the animals to stay in each paddock for a relatively short period of time, usually a week or less. Range or riparian condition is improved by scheduling these short, intense grazing periods at approximately 60- to 90-d intervals.

Because of the short stay and high number of cattle using the designated time control paddocks, the stocking rate under this grazing strategy was equivalent to that used in the deferred rotation treatments, 9 AUMs/hectare. The actual length of stay in each time control paddock was based on the time it took the cattle to utilize 40 to 50% of the riparian forage base.

Livestock exclusion.—The need for livestock control is eliminated by removing livestock grazing from the area. In this study it also provided a means of monitoring the interactive processes between streamflow, channel dynamics, and precipitation.

Summary.—The grazing management strategies applied on Cottonwood Creek differed according to the length of time and livestock density used. Length of time spent grazing a single paddock ranged from 0 d in the livestock exclosures, to 3 - 4 d under time control management, 14 - 28 d under deferred rotation, and 90 d under season-long management. Animal density (numbers per hectare) was nearly the reverse of this pattern. There were 14 head/hectare in the time control paddocks, 3 head/hectare in the deferred rotation paddocks, and 0.2 head/hectare in the season-long pasture. Consequently, results of this study should be viewed in light of livestock density and length of time cattle had access to the riparian area rather than as a recommendation of any particular grazing management method.

Study Design

In June 1986, approximately 12 hectares of Cottonwood Creek and its adjacent uplands were fenced into paddocks for application of deferred rotation, time control, and livestock exclusion management methods. The season-long treatment was represented by the grazing management for the remaining 1,550-hectare pasture surrounding the smaller deferred, time control, and exclusion treatments. Time control paddocks, each about 1.25 hectares, were interspersed among the larger (2.5 hectare) deferred paddocks to achieve some measure of equal variation among all the treatment paddocks (Hurlbert 1984). There were three deferred rotation, eight time control, and two livestock exclusion paddocks (0.75 hectare) lying along Cottonwood Creek. Two monitoring sites, one below and one above the enclosed paddocks, represent the season-long grazing treatment. One riparian exclosure had not been grazed for five years, prior to 1986, and the remaining exclosure was constructed in early 1986.

After the treatment paddocks were constructed, permanent stream channel cross-sectional transects were located in each paddock and pasture to monitor streambank stability. Transects were placed by moving a random number of meters (1 to 10) upstream from the paddock boundary. Thereafter, transects were placed at 15-m intervals. Transects were not located where they would intercept the outside curve of a stream meander. Due to differences in paddock size, the number of transects within paddocks ranged from 3 to 7. There were a total of 62 permanent stream channel transects along the approximately 1 km of stream reach within the study area. Data were collected from each transect following the procedures described by Platts et al. (1983) prior to the grazing season (late May), immediately following completion of grazing within a paddock, and in late October at the conclusion of the grazing season. Because of problems with monitoring schedules and the identification of permanent transects, the data from the newest (1986) exclosure are not included in this paper. Cross-sectional data were first summarized by transect for percent area change by subtracting the post-grazing measurements from the pre-grazing values, summing the resulting differences, and dividing by the summed pregrazing values of the respective transect. In this summary, negative values indicated the channel had experienced erosion while positive values suggested deposition. Then, to account for erosion and deposition events under the same transect which tended to cancel each other out and create a no change signal, absolute values were used in the summary calculations to produce an absolute percent change in channel area. This percentage only indicted whether there had been erosion and/or deposition. It could not indicate whether there had been a change in channel cross-sectional area. To compensate, a third evaluation method, the gini coefficient (Weiner and Solbrig 1984) was also used. This method produced a measure of the channel shape for further interpretation of changes in channel cross-sections. Specifically, a particular cross-sectional area could reflect little or no change in area but having considerable change in shape. The "gini" was used to detect this potential discrepancy (C. Marlow, K. Olson-Rutz, and J. E. Taylor, unpublished). Gini values approaching 0 indicate the channel cross-section is flat and uniform in shape, and values close to 1 indicate a narrow, irregular cross-section.

Streambank moisture levels were measured at 2-week intervals throughout the grazing season to monitor bank susceptibility to trampling deformation (Marlow et al. 1987). A 2-cm × 30-cm soil core was extracted from the streambank within 1 m of each permanent transect stake within each paddock or pasture. Cores were placed in resealable, plastic sandwich bags, returned to the laboratory, weighed to the nearest 0.1 g, dried at 80° C for 24 h and reweighed. Percent moisture was calculated according to Taylor and Ashcroft (1972). An ANOV summarization indicated significant differences ($P = 0.05$) in bank moisture levels among paddocks within treatments, so the data were only used as a covariate in the analysis of streambank stability.

Trout habitat was annually rated in each paddock and pasture following conclusion of the grazing season. The rating was carried out by an independent party (Zone Fisheries Biologist, Gallatin National Forest) using the COWFISH Habitat Capability Model (Lloyd 1986). Habitat suitability criteria for monitoring grazing strategy effects on the stream was used because low flows and shallow conditions precluded a fishery.

Streamflow was continuously measured from early May until late October at two locations, one immediately below and one immediately above the enclosed portion of the study area. Parshall type flumes were placed in the channel so they captured the entire flow. Stevens recorders with a 7-d clock were mounted on the flume and the floats suspended inside a stilling well attached to the side of the flume. The average stage height recorded over each 7-d period was used to calculate stream discharge from the following equation:

$$Q = 2.06 \times H_{1.58}$$

Q represents the stream discharge in cfs (cubic feet/s) and H represents stage height. Cubic feet per second was converted to cubic meters per second by multiplying by 0.028.

Statistical analysis of all data was performed through ANOV and Waller-Duncan *T*-test (Chew 1980) for differences among treatments (grazing methods) within year. The significance level set for this study was $P = 0.10$ (Gill 1981). As previously mentioned, streambank moisture and stream discharge were used as covariates to improve the potential for detecting differences due to stocking rate and livestock density. Means are reported, followed by standard error of the mean in parentheses.

Results

Streambank Stability

We could not detect a difference ($P = 0.30$) in stream channel morphology among the deferred rotation, time control, and livestock exclusion paddocks at the beginning of the study (Ginipre, Table 2). However, at the close of the 1986 grazing season, the channel shape was different among treatments ($P = 0.09$, Ginipost, Table 2). The channel within the exclosure had become deeper and narrower, but the grazed paddocks retained their shape ($P < 0.01$, Ginidiff, Table 2). The percent change in cross-sectional area was minimal and equal among all treatments ($P = 0.21$, net-change-area, Table 2); however, the exclosure experienced more absolute percent change in area ($P = 0.06$, gross erosion+deposition, Table 2) that resulted in a more narrow and deep channel than in the grazed paddocks.

The channel within the various grazing treatments did not change shape from the end of the grazing season in 1986 to early June 1987 (1986 Ginipost, Table 2 versus 1987 Ginipre, Table 3). We began collecting information on channel stability in the season-long pasture in June 1987 and found that the channel lying within this pasture was significantly ($P = 0.05$, Ginipre, Table 3) wider and flatter than the channel within the other grazing treatments. By the end of the 1987 grazing season, the season-long stream channel was somewhat flatter and more uniform than it had been previously ($P = 0.09$, Ginidiff, Table 3). However, this level of change was comparable to that in time control and exclosure paddock. The percent change in cross-sectional area was negligible and equal among treatments ($P = 0.23$), as was gross erosion+deposition ($P = 0.34$, Table 3). Unlike 1986 conditions when the livestock exclusion paddock experienced some downcutting (negative Ginidiff value), the channel in all grazing and nongrazing treatment paddocks and pasture experienced deposition during 1987.

The relative differences among the treatments remained largely unchanged from the post grazing values of 1987 to the pre-grazing values of 1988 (Ginipost, Table 3 versus Ginipre, Table 4). Channel shape changed very little among grazing treatments ($P = 0.36$, Ginidiff, Table 4) after the conclusion of grazing in 1988. Changes in channel cross-sectional area reflected by the net percent change index were all positive, indicating channel aggradation or deposition. However, neither the net change ($P = 0.18$) nor absolute change ($P = 0.29$) were significantly different among treatments. The pattern of the channel becoming more flat and wide in all grazing management treatments noted in 1987 continued in 1988.

Comparison of post grazing channel shape over the first 3 years of this study (Figure 3) indicate that the livestock exclusion and time control paddocks continued to flatten out while the channel in the deferred rotation and season long paddocks remained virtually the same. If narrow, irregular channel profiles are indicative of good riparian condition, then 8 consecutive years of livestock exclusion have not produced an upward or improving trend on Cottonwood Creek.

Trout Habitat Condition

Over the first 3 years of study, trout habitat quality appears to be declining under all of the grazing management methods (Table 5). However, two conditions limit the validity of this interpretation. First, there was a change in U. S. Forest Service fisheries biologists between the 1986 and 1987 habitat inventory which resulted in a major decline in the percentage ratings for all habitat components in 1987. Second, an early, heavy snowfall in 1988 interrupted the inventory process; leaving the last replicates of the grazed paddocks and both of the ungrazed

Table 2.—1986 mean treatment ginicoefficients pre- and post-grazing, within season difference in Gini coefficient, net % change in channel cross-sectional area, and absolute % change in cross-section area, standard error in ( ).

Treatment	Ginipre	Ginipost	Ginidiff	Net % change area	Absolute % change area
Deferred	.21 (.023)^{a}	.21 (.022)^{a}	.003 (.003)^{a}	-2.5 (1.4)^{a}	7.8 (1.4)^{a}
Time-Control	.20 (.018)^{a}	.20 (.017)^{a}	.000 (.002)^{a}	-0.8 (2.7)^{a}	0.8 (1.1)^{a}
Exclosure	.28 (.044)^{a}	.32 (.043)^{b}	-.037 (.006)^{b}	1.0 (1.1)^{a}	15.0 (2.6)^{b}

Different letters within a column denote significance at $\alpha = 0.10$.

Smaller gini coefficient numbers describe flatter, more uniform cross-sectional shape.

Ginidiff = Ginipost - Ginipre, a negative value described a narrowing, deepening channel shape.

A negative net percent change area value represents erosion.

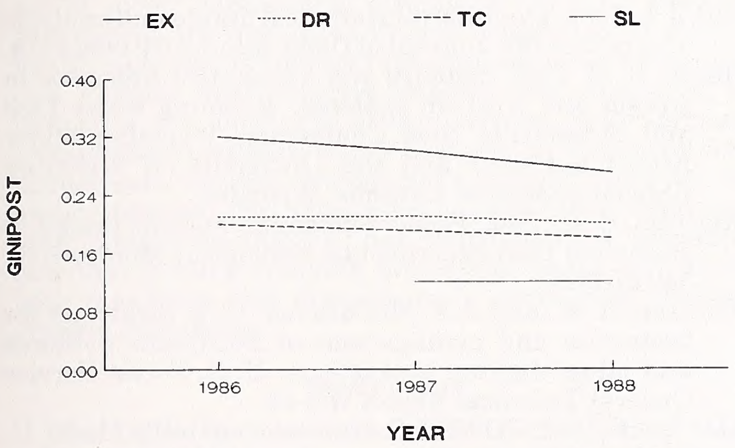
Table 3.—1987 mean treatment channel cross-section variables. See Table 1 for full description.

Treatment	Ginipre	Ginipost	Ginidiff	Net % change area	Absolute % change area
Deferred	.21 (.020)^{b}	.21 (.020)^{b}	.000 (.004)^{a}	0.0 (1.1)^{a}	9.0 (1.2)^{a}
Time Control	.19 (.016)^{b}	.19 (.016)^{b}	.008 (.003)^{ab}	-0.1 (0.9)^{a}	8.4 (0.9)^{a}
Season-Long	.13 (.036)^{a}	.12 (.036)^{a}	.010 (.008)^{b}	3.1 (2.0)^{a}	6.3 (2.0)^{a}
Exclosure	.30 (.039)^{c}	.30 (.039)^{c}	.007 (.008)^{ab}	-2.5 (2.2)^{a}	9.1 (2.2)^{a}

Table 4.—1988 mean treatment channel cross-section variables. See Table 1 for full description.

Treatment	Ginipre	Ginipost	Ginidiff	Net % change area	Absolute % change area
Deferred	.21 (.003)^{b}	.20 (.002)^{b}	+.005 (.002)^{a}	0.4 (2.29)^{a}	8.9 (1.65)^{a}
Time Control	.18 (.013)^{b}	.18 (.001)^{b}	+.005 (.003)^{a}	3.6 (1.63)^{a}	9.0 (1.33)^{a}
Season-Long	.13 (.001)^{a}	.12 (.001)^{a}	+.010 (.001)^{a}	2.2 (1.05)^{a}	5.8 (.30)^{a}
Exclosure	.28 (.002)^{c}	.27 (.002)^{c}	+.008 (.001)^{a}	.21 (1.22)^{a}	5.5 (1.13)^{a}

Figure 3.—Three year trend in post-grazing channel shape for livestock exclusion (EX), deferred rotation (DR), time control (TC), and season-long (SL) paddocks. Lower gini values indicate a more flat and uniform channel cross-sectional profile.



paddocks unsampled. Nonetheless, examination of the 1987 and 1988 data for two-thirds of the treatment replicates indicates a downward trend in percent undercut banks, percent vegetation cover, and habitat optimum (Table 5). Those habitat parameters showing an increase were percent embeddedness and width/depth ratio. Both of these last habitat parameters match the pattern detected while monitoring streambank stability.

Deposition as the predominate agent of change matches the increase in channel gravel and cobble embeddedness and an increasing width/depth ratio follows the trend towards a wider, flatter channel noted with the "gini" analysis of channel cross-sectional area. These changes, coupled with the decrease in percent undercut banks, probably account for most of the apparent decline in trout habitat quality.

Review of the 1987 ratings suggests that livestock exclusion had better values for vegetation cover and bank alteration than did the grazed treatments. Unaltered streambanks did not, however, mean more undercut banks in 1987 (Table 5). During this period, the ungrazed channel had as much embedded material as the channel in the grazed paddocks.

Discussion

After 3 years of below normal stream discharge, the channel of Cottonwood Creek is taking on a wider and more flat cross-sectional profile than had existed previously. This pattern of change will probably reduce the channel's ability to contain high flow events and may lead to the alteration of the floodplain and riparian vegetation (Heede 1986). Cattle use of the riparian zone could tend to hasten this process by accelerating channel aggradation through trampling. This was not supported by the results from this study because the deposition which occurred in the ungrazed paddock was similar to that occurring in the grazed paddocks. The lack of significant differences in channel shape and cross-sectional area among the various grazing treatments combined with the abnormally low stream discharge supports our earlier statements regarding cattle induced damage to streambanks (Marlow et al. 1987).

During periods of high streambank moisture content, cattle use can deform banks, making them more susceptible to erosion during high flow events or causing channels

Table 5.—Mean observed or measured trout habitat values associated with the COWFISH model.

Grazing treatment	Percent undercut banks			Percent vegetation cover			Percent bank alteration			Percent embeddedness (sediment)			Width: depth ratio			Habitat Optimum		
(year)	86	87	88	86	87	88	86	87	88	86	87	88	86	87	88	86	87	88
Deferred rotation	62	19	17	87	43	39	35	28	43	10	47	57	24	14	17	73	53	45
Time control	40	19	11	56	38	45	34	38	35	12	50	64	25	17	25	59	42	33
Season-long	NM	12	8	NM	13	9	NM	69	70	NM	59	57	NM	16	19	NM	37	25
Exclosure	91	6	NM	100	87	NM	3	0	NM	20	67	NM	22	12	NM	84	57	NM

NM = not measured.

to become more flat and wide. Both conditions can upset the dynamic equilibrium of the riparian zone leading to changes in water quality and fisheries habitat. Conversely, grazing when bank moisture levels and stream discharge is low appears to cause no significant changes in either streambank stability or channel shape. Based on the responses during the drought years of 1986 to 1988, grazing did not appear to accelerate channel aggradation above that being caused by low stream discharge. Consequently, the timing of cattle use is critical to the protection and improvement of riparian areas. In addition, on Cottonwood Creek, during periods of low stream discharge, there does not appear to be any significant short-term advantage gained from the removal of livestock.

Low stream discharge may have also contributed to the reduction in undercut banks along Cottonwood Creek. It is difficult to reconcile the loss of undercut banks observed in the trout habitat inventory with the limited change in channel cross-sectional area recorded while monitoring streambank stability without taking the low stream discharge into account. Sediment deposition and a reduced wetted area may have filled in some undercuts while leaving others above the water line. This would have led to a lower estimate of undercut banks within the water column. Loss of undercuts to trampling should have produced a measurable change in channel shape or the level of channel filling. Because we could not detect significant differences in either parameter under livestock grazing, abnormally low stream discharge appears to be the primarily cause of the current decline in trout habitat quality on Cottonwood Creek.

Protection and rehabilitation of riparian areas in semiarid and arid environments may not necessitate automatic reductions in stocking rates or the exclusion of grazing. Instead, managers should schedule grazing of riparian areas for periods of low streamflow and streambank moisture conditions to limit bank degradation. Additional improvement can be attained by basing the stocking rate on the forage availability and utilization of the riparian area rather than holding livestock in the pasture long enough to obtain a pre-determined level of use in the uplands.

Even though the channel in the season long pasture did not experience levels of change significantly greater than that under time control and deferred rotation, it consistently had the greatest amount of change. This suggests that under normal discharge patterns the season-long grazed pasture may experience significant change. In light of this possibility and the low levels of change detected under high cattle densities for short grazing periods (time control), the longer cattle have access to a particular stream stretch, the more likely the occurrence of accelerated channel alteration. Consequently, shortening the grazing period may lead to improvements in riparian zone condition without creating controversy over the elimination of grazing.

At this point in our research, it appears that resource sensitive stocking rates mean the adjustment of the length of the grazing period to coincide with the level of forage utilization in the riparian zone. Resource sensitive management would mean scheduling of grazing for periods when stream discharge is low and banks relatively dry for 2 of 3 years. If there are concerns about potential reductions in the grazing season because of stocking rates being based only on utilization of the riparian forage base, there are at least two management alternatives. First, the riparian zone can be fenced into a special use pasture and grazed according to bank moisture conditions and forage utilization. Second, the pasture or allotment could be subdivided into smaller subunits and grazed under time control management. Each case should improve the opportunity to protect and enhance the riparian zone without causing major reductions in the length of the grazing season. Lastly, it would appear that grazing exclusion should be the management alternative of last resort.

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Grazing and Riparian Management in Southwestern Montana

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Abstract.—A subjective analysis of riparian vegetation response in 34 grazing systems was completed. Most traditional grazing systems developed for uplands did not accommodate riparian recovery. Grazing systems that do not improve riparian vegetation must be documented to avoid their future misapplication. Common denominators to both poor and good riparian management are discussed and recommendations are provided.

The purpose of this paper is to document management observations on long-term livestock grazing management systems where stream riparian resources occur. As is typical of most management situations, data on riparian parameters are somewhat limited, consisting of permanently monumented photographic transects on woody species. Positive woody species response was interpreted as indicative of a successful grazing system. Select grazing system characteristics were compared on successful and unsuccessful systems. Though not a research endeavor, the author believes that management experience, combined with limited monitoring, has value both in providing potential grazing research topics and better insight for both managers and researchers in developing riparian grazing guidelines.

Study Area

The Dillon Resource Area of the Butte District, U. S. Bureau of Land Management, is located in southwestern Montana. Landform is largely foothill and mountain. Climate is typical semi-arid intermountain. Elevation varies from 1,585 to 3,350 m, with most grazing allotments ranging between 1,800 to 2,300 m.

Precipitation in study allotments ranges from 30 to 50 cm per year; however, precipitation in the mountain areas is much greater (120 cm or more). Peak precipitation occurs in May and June. The growing season is short, averaging about 90 d.

Temperatures range from -40° C in winter to 38° C in summer. Freezing temperatures occur as late as mid-June and as early as the first of September.

Most streams are first order through third order tributaries to the Red Rock, Big Hole, and Ruby rivers. Stream gradients are moderate (1-3%).

Upland vegetation is dominated by sagebrush steppe, foothills prairie, Douglas-fir forest, and western spruce-fir associations (Kuchler 1964).

The vegetative aspect of riparian communities is dominated by shrubs, including willows *Salix* spp., alder *Alnus sinuata*, birches *Betula* spp. and dogwood *Cornus stolonifera*. Aspen *Populus tremuloides*, cottonwoods *Populus angustifolia*, *P. trichocarpa*, and juniper *Juniperus scopulorum* occur on small portions of the streams. Riparian herbaceous communities are diverse, with a variety of sedges *Carex* spp., rushes *Juncus* spp., grasses Gramineae, and forbs.

Methods

Stream riparian vegetation response was evaluated on 34 grazing allotments which had grazing management systems of 10 to 20 years duration. Class of livestock was cow-calf pairs or yearling cattle.

Initial condition of stream riparian sites was established through inventories of deciduous woody species and their vigor, age-classes, and utilization using procedures described by Myers (1987). Woody species characteristics on comparison areas plus judgment were used in deriving riparian condition.

Trend in riparian vegetation response was assessed by recording the response of deciduous woody species on permanently established photographic transects using procedures described by Myers (1987). Emphasis was placed on interpretation of photo records duplicated over time. Twelve fenced livestock exclosures were also established in 1981 on a variety of riparian sites. Exclosure sites served as comparison area data sources with which to characterize vegetation recovery and to correlate woody species response with total plant community response.

On one allotment, regrowth and utilization of sedge species was assessed by measuring heights of all plants on paired, 1-m^2 plots, with one being ungrazed (caged) and the other being grazed.

Successful grazing systems were defined as those with good or excellent riparian condition or, if in fair condition, an upward trend and a high rate of woody riparian vegetation response was demonstrated in the photographic transects.

Successful and unsuccessful grazing systems were statistically compared using a two-tailed student's *t*-test for the following characteristics: (1) stocking rates, (2) average number of days provided for regrowth following grazing treatments, (3) average percentage of grazing treatments providing residual herbaceous cover through rest or sufficient regrowth, (4) average days duration of hot season grazing treatments, (5) average days duration of all grazing treatments, and (6) average days duration of fall grazing treatments.

Results

Of the 34 grazing systems evaluated, 25 (74%) were unsuccessful in accommodating a positive riparian vegetation response within a 10- to 20- year period. Upland areas (watersheds) did show positive responses on most of these systems.

Successful systems had lower average stocking rates (4.9 hectares/AUM) than unsuccessful systems (3.8 hectares/AUM) though the difference was not statistically significant. This 22% difference in stocking rate would not be expected to appreciably influence riparian vegetation response to a grazing system.

The success or failure of livestock grazing systems in providing for stream riparian site recovery is related to riparian plant phenology, floodplain function, and livestock use behavior in riparian areas.

Riparian Plant Phenology

Riparian plants sustain a notably longer growing season than do upland plants due to the availability of water. On the study area, upland plants do not provide significant new growth after early July. Limited studies on one allotment showed that sedge species in a riparian site sustained some growth into late September (Table 1). Where a sedge species was grazed to 48% of ungrazed height then rested after 15 June, it regained 86% of ungrazed height by 8 September through regrowth (Table 1). A sedge grazed to only 13% of ungrazed height then rested after 8 September was still able to approximately double its height within 21 d, though this was probably too late in the season to provide significant regrowth (Table 1). Providing for herbaceous regrowth may also extend the growing season rest needed to sustain plant vigor.

Floodplain Function

Stream channels change over time in order to reach equilibrium with varying flow characteristics. Concurrently, streams also have the capability of developing new floodplains (banks) fairly quickly when riparian vegetation slows flood waters and allows suspended sediment to settle.

In Oregon, Elmore and Beschta (1987) documented restoration of major stream banks following 8-15 years of protection. Livestock exclosures in the Dillon study area have also shown major bank building responses since their construction in 1981. Paramount to this function is the presence of dense vegetation on the floodplain during spring flooding events plus vigorous plant growth to stabilize these alluvial deposits. Periodic flooding recharges alluvial deposits, and they become a major water storage area supporting riparian plant communities (Elmore and Beschta 1987; Brinson et al. 1981).

Grazing systems must accommodate this critical function by providing residual cover for sediment filtering and good vegetative vigor for stability. Residual cover is a function of both utilization level and for herbaceous species, post-grazing regrowth. Removing livestock by early August to accommodate at least 30 d of regrowth probably meets floodplain function needs on the study area, though more data are needed (Table 1).

On the study area, successful grazing systems were found to provide for more ($P = 0.05$) post-grazing herbaceous regrowth (34.9 d), compared to only 20.8 d in unsuccessful systems (Table 2). Also, through a combination of both regrowth and rest treatments, successful systems provided post-growing season residual riparian cover 75% of the years, as compared to only 38% of the years in unsuccessful systems (Table 2).

Successful systems provided for floodplain function during most years, plus the residual cover benefited fish habitat through cover, moderation of water temperature, and improvement in the aquatic food chain. Terrestrial wildlife species using riparian sites also benefit from residual cover.

TABLE 2.—Characteristics of successful and unsuccessful grazing systems with means and 95% confidence intervals ( ).

Characteristics	Grazing systems: Successful	Grazing systems: Unsuccessful
Number of grazing systems	9	25
Stocking rates (Hectares/AUM)	4.9 (2.3)	3.8 (1.1)
Days of post-grazing regrowth (up to 9/15)	34.9 (17.8)	20.8 (7.3)
Percentage of grazing treatments providing residual cover through rest or regrowth	74.9 (12.8)	37.8 (13.2)
Duration (days) of hot season (7/1-9/15) treatments	12.5 (10.5)	33.4 (10.4)
Duration (days) of all grazing treatments	28.2 (3.7)	59.3 (8.1)
Duration (days) of fall grazing treatments (8/15-1/10)	21.0 (9.1)	36.5 (8.1)
Percentage of grazing treatments with fall use	31.1 (20.7)	51.1 (9.8)

TABLE 1.—Grazed and ungrazed heights plus regrowth for two sedge species on paired 1-m^2 plots.

		Plant height and grazed height as percentage of ungrazed height			
Dates grazed	Dates measured	Grazed[a] (cm)	Ungrazed (cm)	Grazed[b] (cm)	Ungrazed (cm)
8-15 June	27 June	20.3 (48%)	46.7	25.9 (29%)	89
	8 July	32.5 (63%)	51.6	34.3 (39%)	89
	28 July	41.7 (78%)	53.6	50.5 (54%)	94
	8 Sept.	48.0 (86%)	55.9	59.2 (75%)	79[c]
6 Aug. — 7 Sept.	8 Sept.			8.9 (13%)	65
	29 Sept.			13.7 (24%)	58[c]

[a] *Carex aquatilis*

[b] *Carex rostrata*

[c] Light utilization by big game since last date.

Livestock Use Behavior in Riparian Areas

Livestock utilize riparian sites much more intensively than uplands (Skovlin 1984). Riparian areas provide water, shade, forage diversity, rubbing sites, and sources of succulent forage that uplands provide only seasonally or not at all. In southwestern Montana rangelands, riparian areas sustain almost all of the livestock use during July through early September. This period may be referred to as the hot season. Marlow (1985) documented similar cattle response on small, fenced research pastures in southwestern Montana. Bryant (1979) observed the opposite response in the Blue Mountains of Oregon, with heavy use of riparian areas early in the grazing season and dispersal to uplands slopes during late summer and fall.

Observations in the study allotments showed good dispersal of cattle and use of uplands during spring through early summer until upland forage plants became less succulent, approximately 1 July. Some dispersal of stock occurred in September in response to cooler temperatures and especially in response to precipitation and fall green-up. However, fall dispersal was not as significant as that of spring-early summer.

On the study area, successful grazing systems were found to have significantly ($P = 0.01$) less grazing during the "hot season" (12.5 d) than unsuccessful systems with 33.4 d (Table 2). Likewise, the duration of all livestock treatments was significantly ($P = 0.001$) shorter in successful systems (28.2 d) compared to 59.3 d in unsuccessful systems. Given the reluctance of cattle to disperse from riparian areas, the duration of grazing treatments becomes a key factor in determining the severity of impacts such as trampling and mechanical damage, soil compaction, and utilization. In a rest-rotation system Platts (1981) noted significant riparian habitat alterations at 65% utilization levels, but no detectable impacts at 25% utilization.

Utilization of deciduous woody species appeared to increase sharply as duration of grazing treatments increased, possibly in response to declining herbaceous forage availability. On one allotment with July and August grazing, utilization of willow species increased greatly after 36 d of use (Table 3). This documents the need to adjust the duration of grazing treatments based upon site-specific monitoring results. Each management pasture will likely differ, and a few days' difference in utilization could be significant.

Observations of cattle indicated that utilization of deciduous woody species increased about late August and remained heavy through the fall period. A similar observation was made in Oregon (Kinch 1987). Woody species dominate the aspect of study area streams and have critical roles in riparian site stability and productivity.

On the study area successful grazing systems were found to have significantly ($P = 0.10$) less grazing during the fall period (20.8 d) than did unsuccessful systems with 36.5 d (Table 2). Fall grazing treatments also occurred less frequently (31.3%) in successful systems than in unsuccessful systems (51.1%). A combination of longer duration and more frequent fall grazing deteriorated woody species vigor and regeneration, contributing to diminished floodplain function and reduced riparian dependent values.

Discussion

In the past few years, fisheries biologists have questioned whether grazing systems, especially certain forms of rest-rotation, are providing adequate maintenance or improvement of the aquatic habitat (Skovlin 1984). In southwestern Montana, grazing systems which consider only upland plant growth requirements will generally not meet stream riparian site requirements. The 74% failure rate documented here may be attributed largely to excessive duration in grazing treatments leading to greater physical damage plus deterioration in vegetation vigor, failure to provide residual cover (through regrowth or nonuse) during most years, and excessive use during the hot season and fall periods.

TABLE 3.—Relationship between duration of July-August cattle use and utilization of willows, Sourdough Creek, Montana.

			Utilization[a]	
Year	Days use	Days use/ hectare	*Salix geyeriana*	*Salix boothii*
1984	26	9.9	Trace	1-5%
1986	36	14.1	5-10%	20-25%
1987	38	15.8	30%	45

[a]Ocular estimates on 75 shrubs

Riparian site needs were provided for on successful systems through provision of residual riparian cover and by minimizing the potential adverse impacts resulting from cattle behavior through the design of grazing treatment season and duration.

At the time these grazing systems were developed, the importance of riparian areas was often not recognized, and most managers believed that a single grazing system would meet the needs of all rangeland resources. These "upland grazing systems" were not designed to be responsive to floodplain function, riparian area livestock behavior, nor riparian plant phenology.

Management of riparian sites within a multiple use mandate is one of the most difficult tasks in resource management. Findings here suggest that it can be done, however. Present managers are deeply concerned with answers to the riparian-grazing challenge. Researchers alone cannot provide the answers. Managers must provide insight and practical advice based upon experience with multiple-use management situations, which often differ from carefully controlled research environments. Managers must implement riparian monitoring programs and document both successes and failures in riparian management.

Approaches to riparian management must differ from the traditional approaches to management of uplands, which generally include deferred and rest-rotation principles with long duration grazing treatments and frequent "hot season" and fall grazing. Some well-meaning managers are still implementing "upland grazing systems" in hopes of attaining riparian site recovery.

It is recognized that this analysis is an oversimplification of a complex set of both natural and man-controlled factors. Other factors not considered here also influence the riparian response to a grazing system. These include, but are not limited to:

(1) kind and class of stock
(2) learned behavior of livestock social groups
(3) non-riparian water and shade sources
(4) terrain and weather influences
(5) herding, riding, and salting practices
(6) fencing locations
(7) grazing system compliance
(8) wildlife use, especially beaver and big game
(9) soils

(10) bank and channel vulnerability to detachment
(11) stream gradient and sediment load

Recommendations

Many factors must be considered in managing grazing on stream riparian sites. Some stream systems may be too frail or unstable to warrant grazing use either temporarily or permanently. Special riparian management pastures give the manager much more control in meeting recovery needs, while still allowing livestock use and simplifying management of upland sites.

The following are recommendations for the development of grazing systems where sites are similar to those in southwestern Montana and where stream riparian maintenance or recovery is an objective. Hopefully, research will provide more definitive recommendations in the future.

Provide for residual vegetative cover either through regrowth or rest treatments during at least 75% of the years, or annually if possible. Residual cover needs will vary on different streams. Vigorous woody growth plus at least 15.25 cm of residual herbaceous growth was used with this study.

Through on-site studies, determine how much time is required to provide adequate herbaceous regrowth to meet floodplain function needs and incorporate this into the grazing prescription. Removing stock by about early August was required at the 1,830 m elevation in the study area.

Reduce the duration of grazing treatments to the greatest extent practical. Grazing treatments averaged 28 d in successful systems and 59 d in unsuccessful ones. Many rest-rotation and deferred grazing systems prescribe 60-75 d of use per treatment and are generally unsuitable. Establish suitable length of grazing treatments by monitoring trampling impacts, utilization of woody species, particularly regeneration, plus sufficient time to provide necessary regrowth of herbaceous species.

To the greatest extent practical, design grazing treatments to take advantage of favorable seasonal livestock dispersal behavior. This will vary regionally, based on precipitation patterns and plant phenology. Good dispersal of stock was noted in the study area from early May through early July, and the poorest dispersal was noted during the "hot season" (early July to mid-September). Hot season grazing averaged 13 d in successful systems, compared to 33 d in unsuccessful ones.

Incorporate sufficient growing season rest to provide for good vigor and regeneration in all riparian plants. This does not mean that a full year of nonuse is required. Often, growing season rest can be increased by using pastures more frequently with shorter duration use.

Where deciduous woody species are important in the composition, limit the frequency of fall grazing treatments to about one year in four. Duration of fall treatments should be limited to the greatest extent practical. Fall grazing averaged 21 d in successful systems and 37 d in unsuccessful ones. Close monitoring is required to avoid excessive use on woody species during this period.

Insist upon strict grazing system compliance. A few cattle remaining in a pasture after the prescribed use period can negate the benefits of a good system. Stray animals invariably spend the bulk of their time in stream bottoms. Ninety percent compliance with a grazing system is not adequate.

Standardized approaches to riparian grazing management are not practical. Riparian areas differ in their potential for response and in various unique site factors. These other variables must be considered in the design of a grazing system.

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Effects of Vegetation and Land Use on Channel Morphology

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Abstract.—Spatial and temporal morphologic variability in mountain streams may be attributed to local prevailing conditions. Morphologically distinct reaches of Wickiup Creek, in the Blue Mountains of central Oregon, result from differences in the composition and structure of streamside vegetation, physiography, and land use. Comparisons of grazed and ungrazed meadow reaches and a forested reach loaded with large organic debris reveal specific differences related to the local environmental setting. Overall, width, depth, and cross section area do not increase systematically downstream. The greatest widths are found in the forested reach. Stream depths are at a maximum through the ungrazed meadow reach. Spatial variability results from prevailing vegetation conditions. Temporal variability in the ungrazed exclosure results from the exclusion of livestock and subsequent revegetation of the meadow. Over a 50-year period without grazing, a 94% reduction in channel cross section area occurred.

Spatial variability in a second order, intermontane stream results from differences in the structure and composition of riparian vegetation, presence of embedded organic debris, and local physiography. Temporal variability in channel morphology is largely the result of changes in grazing management.

Several researchers have recognized the contribution of vegetation to fluvial processes and channel morphology. Nanson and Beach (1977) describe the effects of vegetation on channel morphology in northeastern British Columbia, where varying densities of floodplain vegetation are influencing overbank sedimentation rates. The character and species of vegetation also contributes to variability in channel morphology. In Vermont, small streams flowing through sod tend to be narrower and deeper than streams under forest cover (Zimmerman et al. 1967). Forested reaches of stream tend to have highly variable widths as a result of local disturbance. Smith (1976) observed the role of vegetation in reducing bank erosion and subsequent lateral migration of a glacial meltwater channel. Erosion rates drop with increases in root mass in channel bank sediments, as channel bank roots protect against fluvial erosion and anchor against collapse (Smith 1976).

Large organic debris, derived from streamside vegetation, influences channel morphology by protecting streambanks and increasing channel roughness. Further, woody debris helps control the routing of sediment and water (Swanson et al. 1982). In steep mountain streams, organic debris controls local stream morphology by trapping sediment and creating plunge pools (Keller and Swanson 1979). Log steps provide local control of base level and serve to decrease channel gradients (Heede 1985). In a coastal redwood environment, 60% of the total drop in channel elevation is associated with instream debris (Keller and Tally 1979).

Historic channel changes often obscure longer term channel evolution. Gregory (1984) and Hickin (1983) concluded that most rivers are dominated by transient behavior and never fully adjust to major climatologic events or land use change. Historic channel adjustments have been further linked to the growth and decline of bank and floodplain vegetation. Hadley (1961) and Graf (1978) describe channel narrowing and deepening in response to the progressive spread of tamarisk in the southwestern USA.

The effects of livestock grazing on stream ecosystems are receiving attention from researchers in many fields. Biologists have long been aware of grazing impacts on fisheries resources (Platts 1979). Livestock effects can be divided into impacts on streamside vegetation and impacts on the adjacent channel. Vegetation is altered by soil compaction, selective herbage removal, and physical damage by trampling and rubbing (Kauffman and Kreuger 1984). Impacts on the stream channel include increased channel bank instability, channel shape adjustments, and changes in sediment and discharge volumes (Platts 1979). Downstream from a fenced reach of stream in eastern Oregon, Winegar (1977) found reduced sediment loads. By 1978, 9 years after the establishment of the exclosure, up to 3 m of material had aggraded within the exclosed reach (Winegar 1977).

The recognition of temporal and spatial morphologic variability in mountain streams presents a challenge to the application of conventional analytic techniques. For example, the quasi equilibrium state described by downstream hydraulic geometry (Leopold and Maddock 1953) may not accommodate the range of natural variability that is found in mountain streams. Conventional analysis such as hydraulic geometry is directed towards quantifiable deterministic solutions and may ignore processes which cause deviations from predicted trends (Hickin 1984).

The identification of the causes of morphologic variability, such as vegetation, basin characteristics, and land use, will contribute towards a broader understanding of change in the natural environment as well as provide a gage for evaluation of responses to management activities. Land management goals on public lands are evolving to include multiple resource management of fisheries, wildlife, and recreation, in addition to the traditional uses of timber and range. Federal land management agencies are developing strategies for streamside management (Beschta and Platts 1986), but it may not be possible to enhance all stream resources simultaneously.

Study Area

Wickiup Creek is a second order tributary to the Silvies River in central Oregon and has a drainage area of 24 km^2 (Figure 1). The study basin lies at an average elevation of 1,650 m above mean sea level and is largely forested (95%) with mixed stands of ponderosa pine *Pinus ponderosa*, lodgepole pine *Pinus contorta*, grand fir *Abies grandis*, and Douglas fir *Pseudotsuga menziesii*. The drainage basin is characterized by steep forested slopes and narrow alluvial valleys. At its headwaters, Wickiup Creek is ephemeral, flowing through forested reaches. Downstream, flow becomes intermittent to perennial. The valley widens into open, sagebrush *Artemisia* spp. meadows and a meandering pattern is established. Streamside vegetation consists of annual and perennial herbaceous vegetation, occasional thickets of willow *Salix* spp., and stands of mixed conifers, predominantly lodgepole pine. Seasonal livestock grazing and timber harvest constitute the principle land use activities in the study area. The basin falls within a larger cattle allotment that is divided into six pastures and is currently managed under a rest-rotation grazing system. In 1938, the county agricultural agent and U. S. Forest Service personnel cooperated in the construction of a 2.8-hectare fenced livestock exclosure on Wickiup Creek to demonstrate the effects of grazing on forage production.

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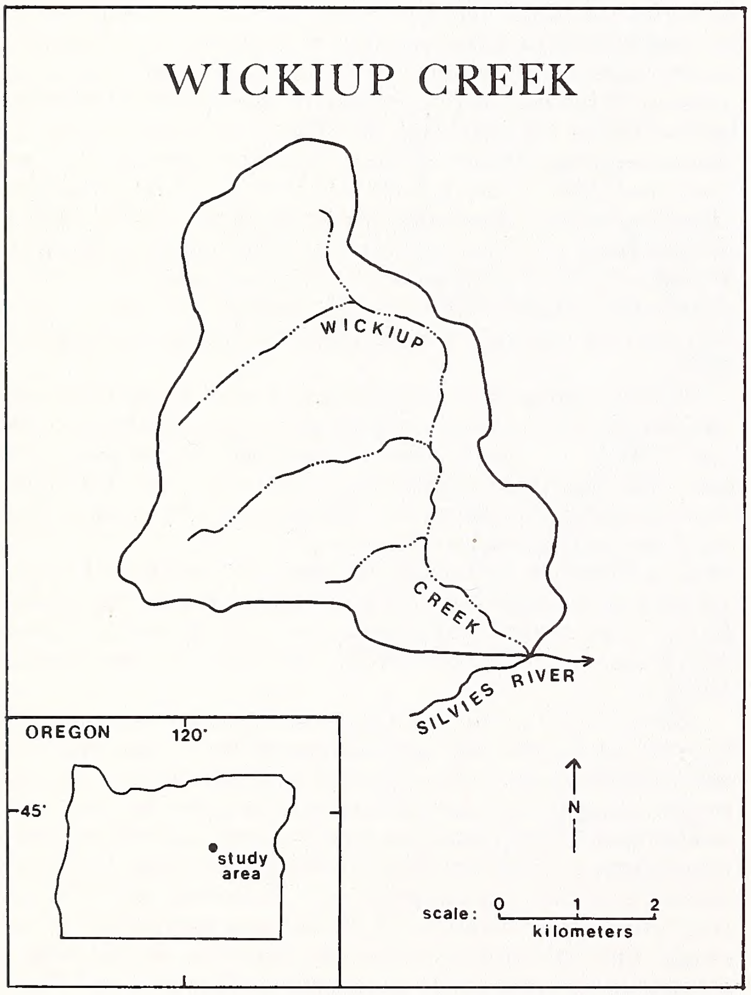
Figure 1.—Location of study area.



Study Reaches

In order to establish patterns of channel morphology and evaluate sources of variability, the length (9.2 km) of Wickiup Creek was divided into five study reaches (Figure 2). A reach was identified as having similar physiography, vegetation, channel pattern, and land use treatment (Table 1).

Figure 2.—Study reaches and location of selected channel cross section survey sites.

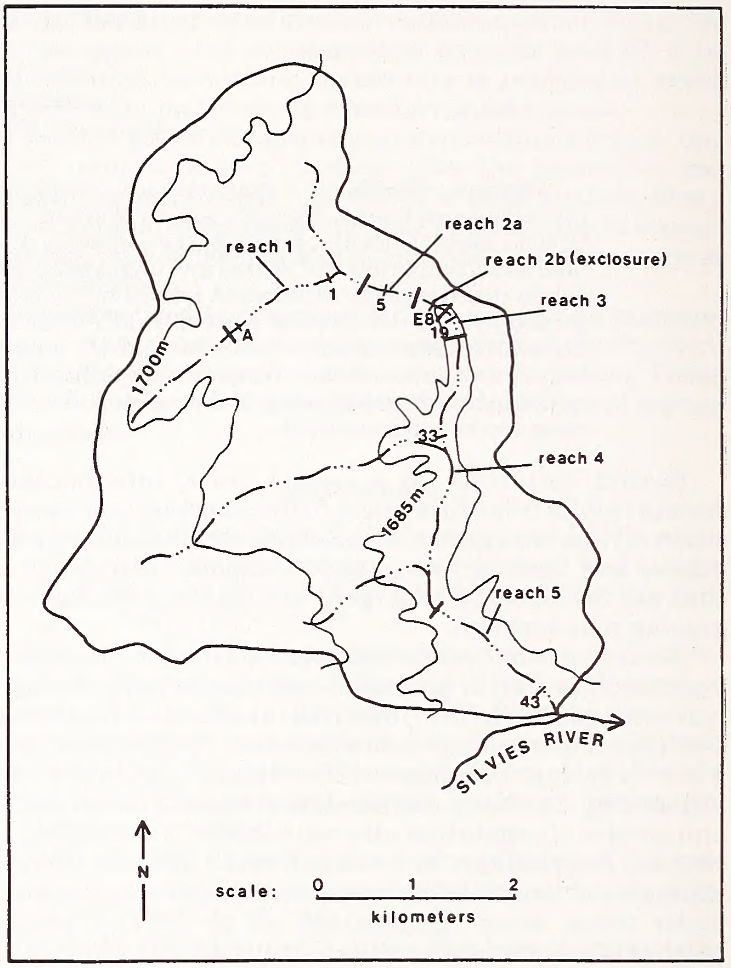


Table 1.—Summary of principle reach characteristics.

Reach	Distance downstream (meters)	Description
1	2,414-3,863	Steep, forested, headwater channel; ephemeral to intermittent flow.
2a	3,863-4,255	Moderate slope, meadow, mid-basin channel; intermittent to perennial.
2b	4,255-4,705	Exclosure channel-same as 2a.
3	4,705-5,538	Moderate slope, forested reach, embedded large organic debris; perennial flow.
4	5,538-8,153	Moderate to gentle slope, meadow-forest, valley widening; perennial.
5	8,153-9,300	Moderate to gentle slope, meadow; perennial flow.

Methods

Field sampling and historic documentary evidence were combined for the purpose of identifying stream channel interactions and response to riparian vegetation, physiography, and livestock grazing. Field data recovery was based on the establishment of representative cross section survey sites at intervals along Wickiup Creek (reaches 1, 4, and 5). Reaches 2 and 3 were intensively surveyed at 30-m intervals, and constitute the focus of this investigation. Reach 2 consists of two meadow sections, grazed (2a) and ungrazed (2b). Historic documentary evidence consists of a 50-year photographic record of channel changes within the exclosure spanning the period 1933 to 1985. Estimates of historic channel widths and depths were obtained from repeat photographs for the years 1933, 1948, 1956, and 1980.

A consistent morphologic level, the bankfull level, was identified in the field by banktop, vegetation change, and top of gravel bar. Seven variables describing channel morphology were determined from channel cross section plots and consist of: width, cross section area, mean depth, maximum depth, wetted perimeter, hydraulic radius, and width:depth ratio. Additional variables include channel slope, determined from field survey and topographic maps, channel roughness, determined by a combination of established methods (Cowan 1956; Barnes 1967), velocity, determined from the Manning equation,

$$V = (R^{0.67}\ S^{0.50})/n$$

and discharge determined from the continuity equation,

$$Q = V * A$$

where,

V = velocity (m/s)
R = hydraulic radius (m)
S = channel slope (m/m)
n = Manning's roughness coefficient
Q = discharge (m^3/s)
A = area (m^2)

Discharge estimates were verified by comparison with regionally derived flood discharge equations (Harris and Hubbard 1983).

Analysis and Results

In a conventional analysis of downstream hydraulic geometry, independent basin variables such as drainage area or distance downstream are used to evaluate systematic adjustments in channel morphology and discharge (Leopold et al. 1964). A regression analysis of the seven morphologic variables, velocity, and discharge against distance downstream reveals the absence of systematic trends ($R^2 < 0.10$), with the exception of channel area and discharge (Table 2). Very gradual increases in area and discharge with distance downstream are evident from the regression equations; however, the low level of explained variance indicates the influence of other factors. The degree to which vegetation and livestock influence channel size, shape, roughness, and velocity were examined by comparing individual reaches.

Reach Morphology

The means and standard deviations of the morphologic variables were compared by reach (Table 3). The level of between group variance is determined from an analysis of variance in which the means and standard deviations of five groups (reaches of Wickiup Creek) are compared. The null hypothesis is that there are no differences in the character of individual reaches. The analysis tests this hypothesis by comparing variation between groups to variation within groups due to random error. Significant differences ($P \leq 0.05$) are found to exist for all the morphologic variables (Table 4). The null hypothesis, therefore,

Table 2.—Regression analysis of downstream channel morphology and Discharge[1].

Variable	Regression equation	r^2	SE	F	P
Width	=.094+.000044(D)	5.2	.24	4.2	.05
Depth 1 (mean)	=.633+.000014(D)	0.0	.18	0.8	Not Sig.
Depth 2 (max.)	=.462+.000011(D)	0.0	.15	0.7	Not Sig.
Wet. per.	=.206+.000036(D)	6.8	.18	5.3	.05
Area	=-.54+.000058(D)	17.3	.18	13.2	.001
Hyd. rad.	=-.74+.000021(D)	4.4	.12	3.7	.10
Width:depth	=.705+.000030(D)	0.0	.38	0.8	Not Sig.
Velocity	=-.37+.000048(D)	7.5	.23	5.7	.05
Discharge	=-.91+.000011(D)	16.1	.34	12.1	.001

wet. per. = wetted perimeter, hyd. rad. = hydraulic radius, D = distance downstream, n = 59.

[1] Analysis of log ten values.

Table 3.—Analysis of grouped morphologic data — means (x) and standard deviations (sd).

Reach		Width	Depth (mean)	Depth (max.)	Wet. per.	Area	Hyd. rad.	W:D
1	x	2.42	0.31	0.42	2.87	0.77	0.28	8.10
	sd	0.60	0.08	0.16	1.07	0.34	0.08	2.52
2a	x	2.01	0.25	0.38	2.24	0.47	0.21	9.39
	sd	0.40	0.08	0.11	0.46	0.14	0.06	4.40
2b	x	1.21	0.41	0.50	1.71	0.43	0.26	2.62
	sd	0.79	0.13	0.16	0.64	0.16	0.05	1.39
3	x	3.34	0.22	0.35	3.42	0.67	0.21	18.14
	sd	1.75	0.08	0.13	1.69	0.26	0.07	13.64
4	x	3.28	0.26	0.40	3.40	0.81	0.25	13.49
	sd	0.88	0.07	0.10	0.88	0.18	0.06	9.13
5	x	3.02	0.45	0.59	3.46	1.44	0.38	7.32
	sd	1.27	0.18	0.27	1.25	1.23	0.15	3.23

Wet. per. = wetted perimeter, Hyd. rad. = hydraulic radius, W:D = width depth ratio.

All data in meters.

Table 4.—Analysis of variance — grouped morphologic data.

	Actual		Residual	
Variable	F	P	F	P
Width	6.96	.001	9.66	.001
Average depth	7.63	.001	6.03	.001
Maximum depth	3.22	.05	2.23	Not Sig.
Wetted perimeter	5.37	.001	5.59	.001
Cross section area	5.68	.001	3.28	.05
Hydraulic radius	5.20	.001	2.64	.05
Width:depth	5.71	.001	13.53	.001
Velocity	17.54	.001	12.03	.001
Discharge	16.60	.001	11.19	.001

can be rejected supporting the contention that differences in between-group channel morphology are representative of real differences in the morphology of Wickiup Creek. In sum, the results of the analysis of variance support the differentiation of reaches based on the following criteria: drainage basin characteristics, vegetation, and management treatment.

Results of Fisher's LSD Test

A more complete picture of the differences between individual groups emerges following application of Fisher's LSD test (Table 5). The means of each group are ranked from smallest to largest, and coded A through F. An "S" indicates that the mean is significantly different from the corresponding level. For reaches 2a, 2b, and 3, width and width:depth ratios are significantly different. For all morphologic variables except cross section area, the forested reach (3) and the grazed meadow reach (2a) are significantly different. All levels are not significantly different in all cases.

Downstream Effects

In order to account for the downstream effects of increasing drainage area, an analysis of variance was performed on standardized regression residuals. By analyzing regression residuals, the effects of increasing drainage area are removed, isolating variability due to other factors. The residuals are grouped by reaches, and the means and standard deviations compared. Again, significant differences ($P \leq 0.05$) are found, further supporting the characterization of reach morphology.

Comparing actual values and standard residuals (Table 4) reveals a decrease in the level of explained variance for depth, area, and hydraulic radius, suggesting a dependence on the downstream effects of increasing drainage area. An increase in the amount of explained variance is apparent for width, wetted perimeter, and width:depth ratio, indicating a dependence on local factors. Removing the downstream effects of increasing drainage area isolates those variables most responsive to local vegetation conditions and management treatment. Width, wetted perimeter, and channel shape, therefore, reflect local variability of streamside vegetation and intensity of livestock use.

Changes in Channel Morphology by Reach

The headwater, ephemeral channel (reach 1) of Wickiup Creek is relatively wide and enlarged, probably reflecting more infrequent flow events. Downstream, through reach 2a, the channel is intermediate in width and shallower

Table 5.—Differences between individual groups — results of Fisher's LSD Test.

Width									**Mean depth**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	1.21	.	S	S	S	S	S	A	3	0.22	.	.	.	.	S	S
B	2a	2.01	S	.	.	.	S	S	B	2a	0.25	.	.	.	.	S	S
C	1	2.42	S	.	.	.	.	.	C	4	0.26	.	.	.	.	S	S
D	5	3.02	S	.	.	.	.	.	D	1	0.31	.	.	.	.	S	S
E	4	3.28	S	S	.	.	.	.	E	2b	0.41	S	S	S	S	.	.
F	3	3.34	S	S	.	.	.	.	F	5	0.45	S	S	S	S	.	.
Maximum depth									**Wetted perimeter**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	3	0.35	.	.	.	.	S	S	A	2b	1.71	.	.	S	S	S	S
B	2a	0.38	.	.	.	.	S	S	B	2a	2.23	.	.	.	S	S	S
C	4	0.40	.	.	.	.	.	S	C	1	2.87	S	.	.	.	.	.
D	1	0.42	.	.	.	.	.	.	D	4	3.4	S	S	.	.	.	.
E	2b	0.50	S	S	.	.	.	.	E	3	3.42	S	S	.	.	.	.
F	5	0.59	S	S	S	.	.	.	F	5	3.46	S	S	.	.	.	.
Area									**Hydraulic radius**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	0.43	.	.	.	.	.	S	A	3	0.21	.	.	.	S	.	S
B	2a	0.47	.	.	.	.	.	S	B	2a	0.21	.	.	.	.	.	S
C	3	0.67	.	.	.	.	.	S	C	4	0.25	.	.	.	.	.	S
D	1	0.77	.	.	.	.	.	S	D	2b	0.26	S	.	.	.	.	S
E	4	0.81	.	.	.	.	.	S	E	1	0.28	.	.	.	.	.	S
F	5	1.44	S	S	S	S	S	.	F	5	0.38	S	S	S	S	S	.
Width:depth ratio									**Velocity**								
Level	Reach	Mean	A	B	C	D	E	F	Level	Reach	Mean	A	B	C	D	E	F
A	2b	2.62	.	.	.	S	S	S	A	2b	0.52	.	.	S	S	S	S
B	5	7.32	.	.	.	.	.	S	B	3	0.66	.	.	.	S	S	S
C	1	8.10	.	.	.	.	.	S	C	2a	0.75	S	.	.	S	S	S
D	2a	9.39	S	.	.	.	.	S	D	5	1.06	S	S	S	.	.	.
E	4	13.49	S	.	.	.	.	.	E	4	1.31	S	S	S	.	.	.
F	3	18.14	S	S	S	S	S	.	F	1	1.62	S	S	S	S	.	.

than adjacent reaches. By comparison, the exclosure channel (reach 2b) consists of a narrow and deep channel. Through the forested reach (reach 3) the channel is wider and shallower than adjacent reaches, and, in the downstream reaches of Wickiup Creek (reaches 4 and 5), a narrower deeper channel with gradually increasing cross section area is evident.

Differences in mean reach velocities are also evident, comparing the exclosure against adjacent reaches. Mean velocities are lowest in the exclosure (0.5 m/s) compared to upstream (0.8 m/s) and downstream (0.7 m/s). Through the exclosure reach, velocities are reduced by thick channel bank vegetation which offers greater resistance to flow.

Selected cross section plots illustrate changes in channel morphology through reaches 2a, 2b, and 3 (Figures 3-5). Reaches 2a and 3 exhibit inset bankfull channel cross sections within enlarged cross section areas. No inset channel is evident through reach 2b, suggesting aggradation of bed and banks. Valley and channel bed profiles show a bulge in the bed profile corresponding to the exclosure (Figure 6). Approximately 1 m of sediment has accumulated within the exclosure, the result of filtering by channel bank vegetation and reduced velocities.

Figure 3.—Selected channel cross section plots: Reach 2a.

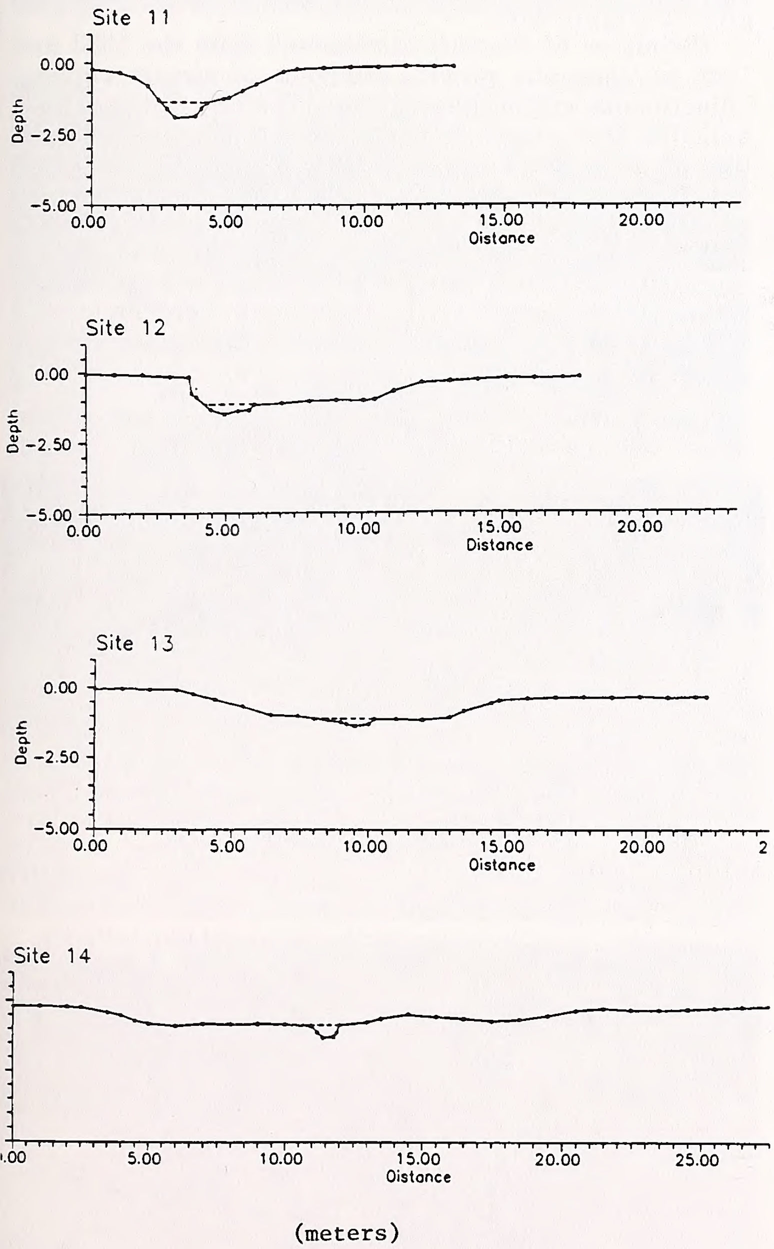


Figure 4.—Selected channel cross section plots: Reach 2b (exclosure).

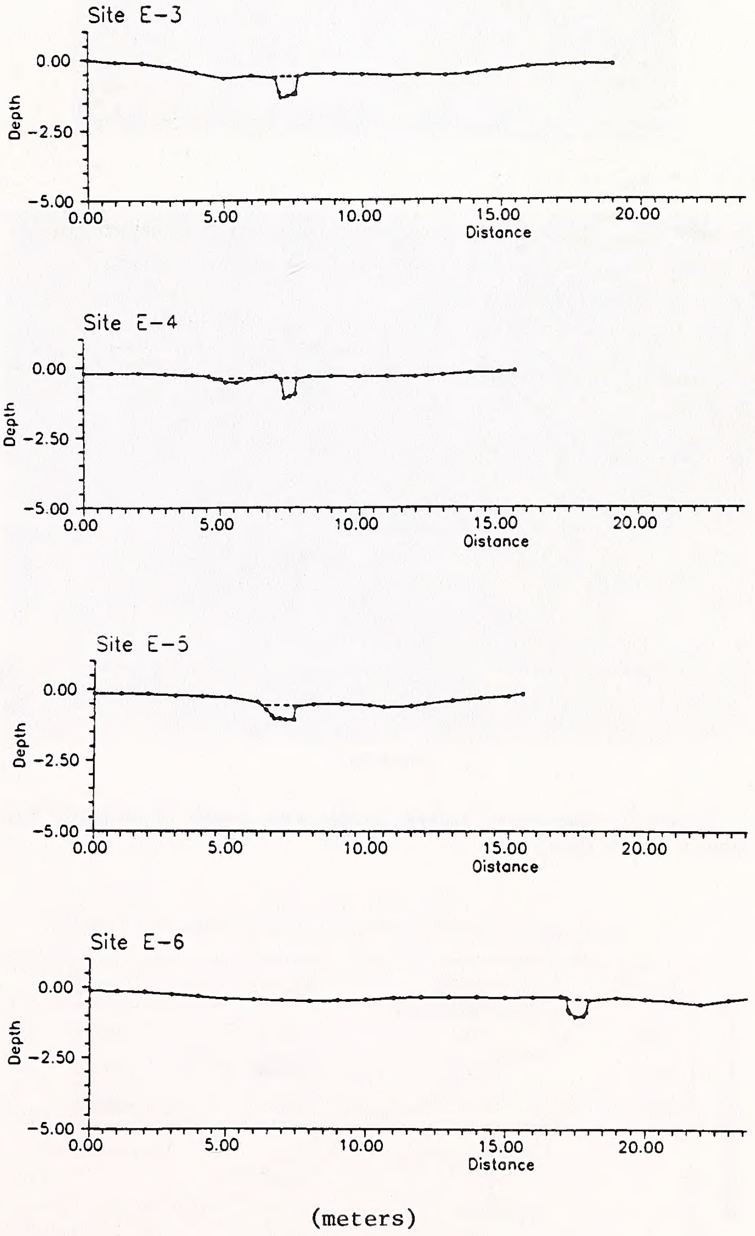


Figure 5.—Selected channel cross section plots: Reach 3.

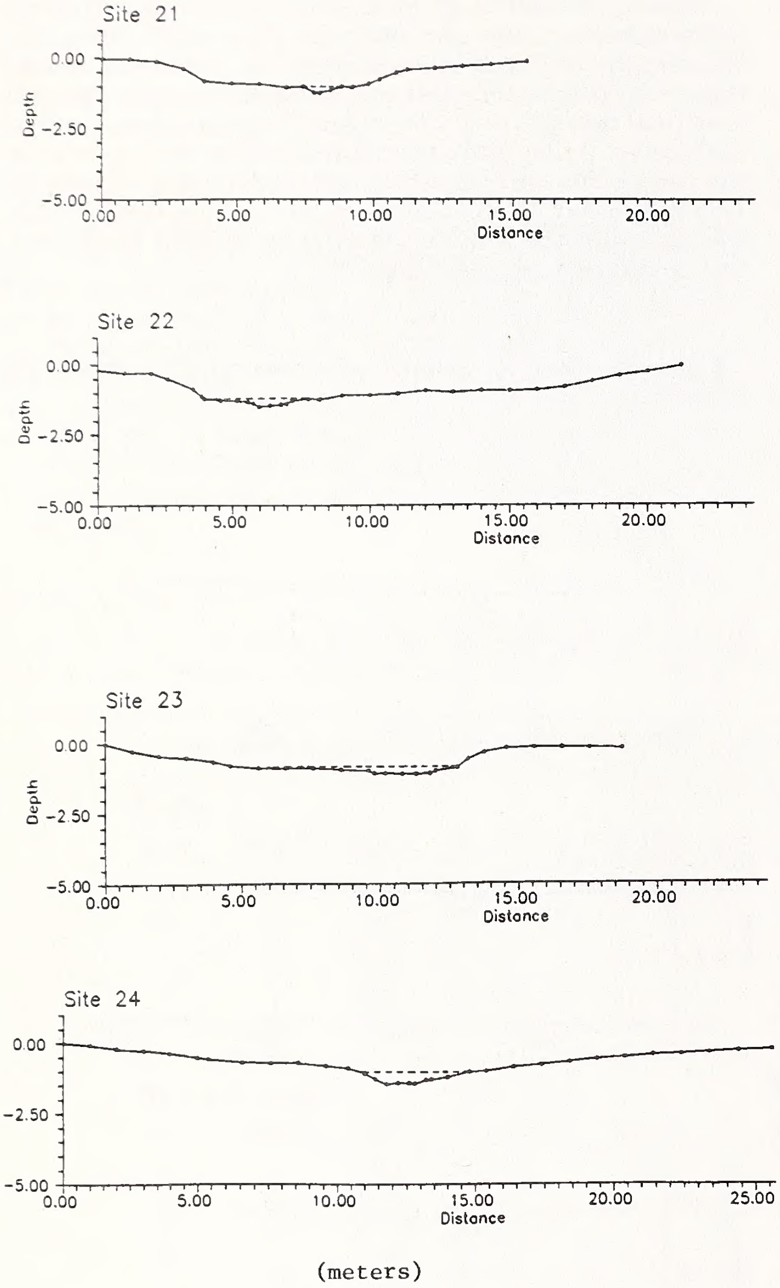
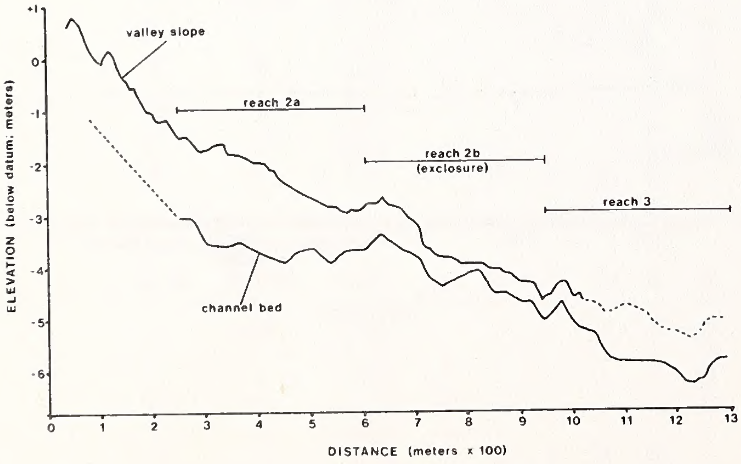


Figure 6.—Surveyed valley profile and depth of channel bed below valley floor.



Historic Channel Change

Historic photo documentation in the exclosure (reach 2b) provides information on vegetation trends and morphologic adjustments. Prior to the establishment of the exclosure, the meadow appears barren of vegetation and mineral soil is exposed (Figure 7a). The stream channel has banks approximately 1.3-m high. No channel bank vegetation is evident, and the channel has a trapezoidal shape with outsloped banks (Figure 7b). By 1948, 10 years after the establishment of the exclosure, the meadow had revegetated, the channel bed had aggraded approximately 0.60 m, and vegetation had become reestablished on the channel banks (Figures 8a and 8b). Continued revegetation occurred in the exclosure after 1948 so that, by 1956, the channel banks were partially obscured by thick bank vegetation and the channel was still narrower (Figure 9a). Willow, completely absent in 1933, gradually recovered. By 1980 the channel is almost completely obscured by grasses and sedges, and willow thickets are evident in the foreground (Figure 9b).

Estimates of channel dimensions from the 1933 and 1948 photographs provide evidence of stream channel adjustments within the exclosure (Table 6). Between 1933 and 1948 there was a 64% reduction in channel cross section area. Between 1948 and 1986, a cross sectional area reduction of 82% occurred. Overall, in 50 years without grazing, a 94% decrease in channel area occurred. Although the figures are estimates only, the total reduction represents an order of magnitude change in channel area. Channel adjustments in the exclosure are predominantly the result of the absence of livestock and channel bank revegetation.

Figure 7.—Historic photos of exclosure: overview and channel prior to fencing, 1933. (Malheur National Forest Files).

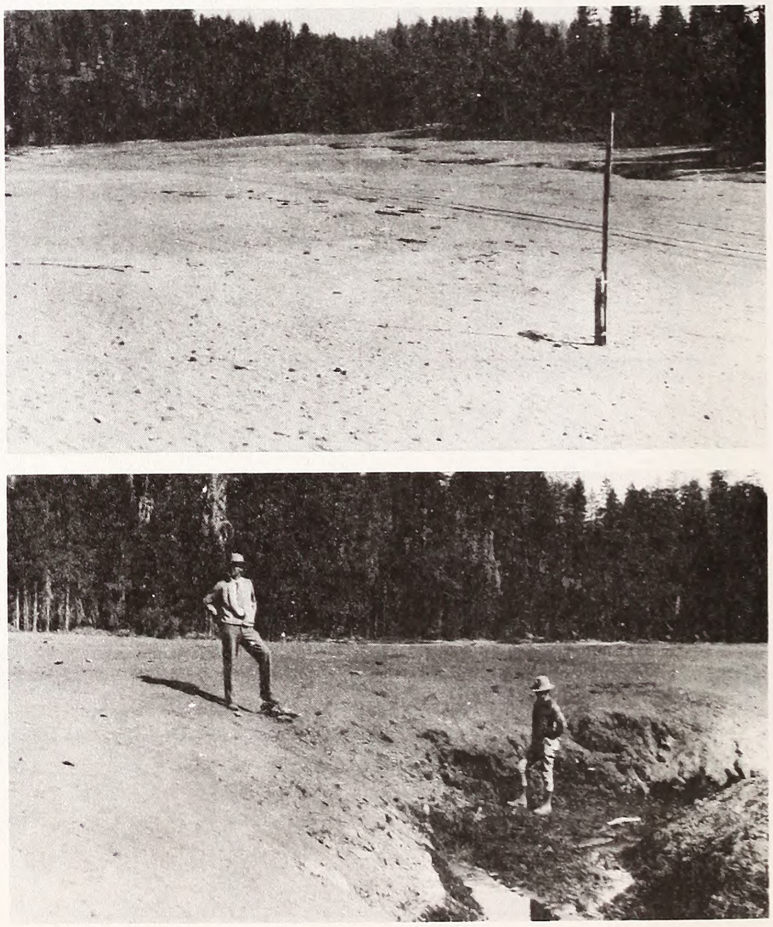
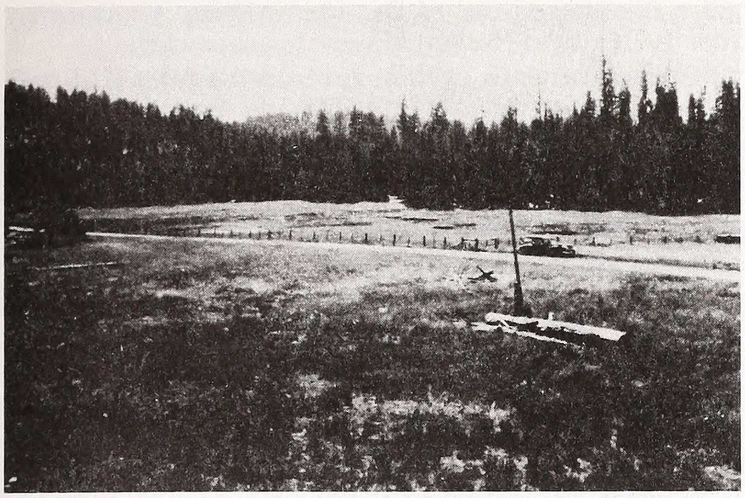


Figure 8.—Historic photos of exclosure: overview and channel following fencing, 1948. (Malheur National Forest files).

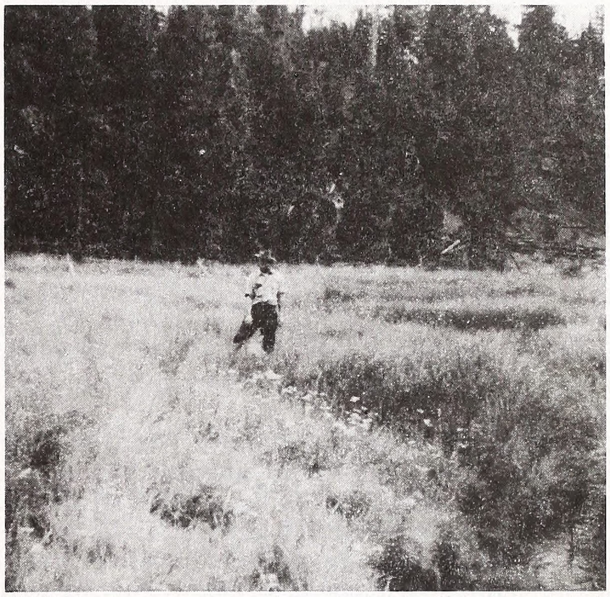


Discussion and Conclusions

Morphologic variability in mountain streams limits conventional analysis of downstream channel geometry based on regular, continuous adjustments of width, depth, and capacity. Scatter in downstream plots is often attributed to multivariate control of channel morphology (Richards 1982). Vegetation and land use activities contribute to deviations from predicted trends (Mosley 1981).

Spatial and temporal adjustments in the morphology of Wickiup Creek are largely the result of vegetation structure and composition, local physiography, and livestock use. Dense bank vegetation, in the ungrazed reach, has produced a narrow and deep channel. Channel bank vegetation traps suspended sediment and increases bank strength, producing aggradation of the bed and banks. Abundant grasses and sedges growing in the channel offer greater resistance to flow further reducing fluvial erosion by decreasing velocities. Zimmerman et al. (1967) reported similar findings on the differential influence of forest and meadow vegetation on the morphology of small headwater streams in northern Vermont. Overall, width and depth did not increase systematically downstream (Zimmerman et al. 1967).

Figure 9.—Historic photos of channel in exclosure: 1956 and 1980. (Malheur National Forest files).



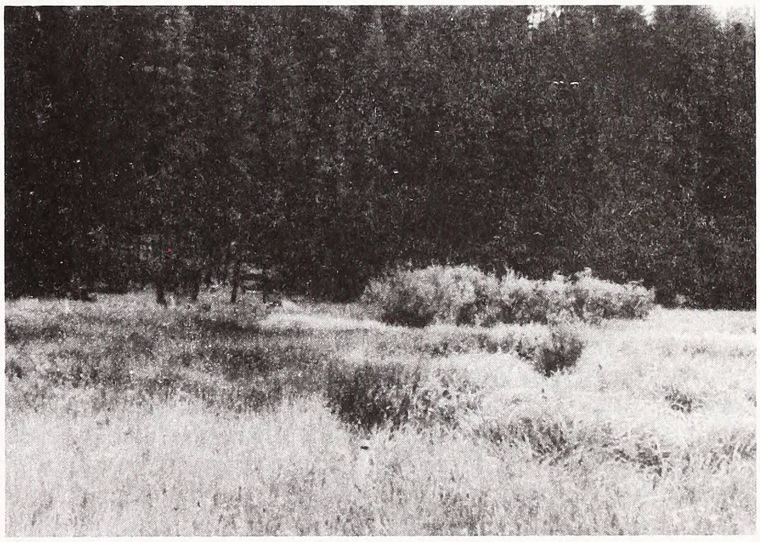


Table 6.—Historic channel adjustments — reach 2b.

Year	Width	Depth	Area
1932	5.25	1.30	6.83
1948	3.50	0.70	2.45
1986[1]	3.50	0.12	0.43

[1] field survey

Through the forested reach, channel shape is highly variable. An abundant supply of organic debris effects channel form and fluvial processes by providing sites for deposition, locally reducing or enhancing bank erosion, and dissipating stream energy (Keller and Swanson 1979). Typically, channel widths increase upstream from blockages, and depths are locally enhanced in plunge pools downstream. Elevation changes associated with embedded organic debris dissipate erosional energy.

Historic adjustments in the morphology of Wickiup Creek were observed in the exclosure. Historic photos show a dramatic change in vegetative cover from 1933 to 1980. In 1933 the entire reach and adjacent meadow were barren of vegetation. Cattle were excluded in 1938, and by 1948 the site had revegetated and the channel had narrowed and deepened. By 1986 the channel had undergone an order of magnitude reduction in bankfull channel cross section area. Today, thickly vegetated overhanging banks obscure a narrow and deep channel.

On Camp Creek in central Oregon, Winegar (1977) described the recovery of a reach excluded from grazing in the 1960s. Winegar emphasized the function of riparian vegetation in channel stabilization and sediment deposition. Sediment load sampling along Camp Creek indicated significant reductions in suspended load occurring through 5.6 km of protected stream. The exclosure on Wickiup Creek is also functioning as a sediment trap, as indicated by changes in channel morphology. The principle non-fluvial effects of streamside vegetation are anchoring of channel banks and trapping sediment. Vegetation influences hydraulic interactions by contributing roughness elements and shear strength to the channel boundary. Increased roughness increases resistance to flow and promotes sediment deposition through reduced competency.

In conclusion, the channel morphology of Wickiup Creek shows a high degree of variability when examined by reaches of relatively uniform characteristics. Conventional plots of morphologic variables such as width and depth against distance downstream do not exhibit strong systematic trends because of the small size of the drainage basin (24 km^2) and because of the overwhelming influence of local vegetation and land use. Specifically, width, wetted perimeter, and channel shape are most responsive to local variability of streamside vegetation and intensity of livestock use. Where Wickiup Creek flows through the ungrazed exclosure the channel is narrow and deep, the result of thick bank vegetation promoted by the absence of livestock. In the forested reach the effects of downed timber are reflected in the channel morphology; the stream is wider and shallower and exhibits a variable channel shape. Large organic debris deflects channel flow and controls the routing of sediment down-channel.

Traditionally, mountain regions in the West have been exploited for their forage, timber, and mineral resources, often at the expense of the stream and riparian environment. Alternative values such as wildlife and recreation are gaining attention. In addition, there is growing concern over quantity and quality of water supply for downstream users. Studies of small mountain stream systems provide insight into sources of variability in channel morphology and fulfill a more immediate need for an understanding of the functioning of mountain streams for improved management.

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Streamside Zones and Wildlife in Southern U. S. Forests

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Abstract.—Strips of mature trees, retained along intermittent streams when stands are harvested and planted to pine, reduce effects of nonpoint pollution and enhance wildlife habitat. The Southern Forest Experiment Station is investigating the effects of extent and composition of streamside zones (SZ) on vertebrate wildlife communities in pine forests in southern USA. Specifically, relative animal abundance was related to narrow (7-23 m), medium (31-40 m), and wide (52-93 m) SZ. Virtually no squirrels or squirrel nests were found in SZ less that 40 m wide but were common in those > 50 m wide. Amphibians and reptiles were abundant in medium and wide SZ (wider than 30 m), which were characterized by a canopied overstory, shaded understory, and leaf litter. Amphibians and reptiles were low in abundance in the dense brushy narrow zones with logging slash, but this habitat supported the highest abundance of small mammals.

Many mature forests in southern USA are being cut and replaced by pine plantations. This conversion is a drastic habitat alteration for wildlife. In the young brushy stage, these plantations are good habitat for a variety of wildlife associated with early successional stands. Total forage often surpasses 3,000 kg/hectare, and fruit or soft mast yields approach 100 kg/hectare (Stransky and Roese 1984). White-tailed deer *Odocoileus virginianus* and cottontail rabbits *Sylvilagus floridanus* fare well in young clear-cut areas. Small mammals, such as cotton rats *Sigmodon hispidus* and harvest mice *Reithrodontomys* spp., are abundant (Fleet and Dickson 1984), and a diverse and abundant bird community inhabit these stands (Dickson and Segelquist 1979). However, dense young stands are not suitable for all wildlife, and wildlife habitat for most species deteriorates after about 10 years when pine canopies close and shade out understories of non-pine vegetation.

Streamside Zones

When mature stands are harvested and regenerated, strips of mature trees along permanent and intermittent streams bisecting or adjacent to the stands may be retained to reduce soil erosion (Miller 1987) and to enhance wildlife habitat (Dickson and Huntley 1987). These areas of hardwood or mixed pine-hardwoods are called riparian zones, stringers, streamers, or streamside zones (SZ). These zones traverse young stands and create habitat diversity and edge, which are important to many species of wildlife. The SZ function as travel corridors for animals between stands and may help to maintain genetic contact between potentially isolated populations in adjacent mature stands, thereby helping to maintain population genetic viability (Harris 1984). These zones may also provide limited habitat for species associated with mature forests, such as the pileated woodpecker *Dryocopus pileatus*. Nesting sites, food, and cover probably are maintained for many species of wildlife. Fruit is produced by the residual trees and nesting and foraging sites are available in the shrub and canopy vegetation. In Mississippi (Warren and Hurst 1982) and in eastern Texas (McElfresh et al. 1980), squirrel *Sciurus* spp. use of SZ was much higher than in adjacent upland stands. In both studies, squirrel abundance was high in wide SZ (40-141 m). There were no data on SZ width as a limiting factor for squirrel habitat suitability. Mesic sites along intermittent streams usually have fertile soils that support a luxuriant growth of vegetation that produce high yields of a variety of forage and mast and also provide escape cover for deer (Halls 1973). Floodplain forests downstream from SZ support more birds than do upland pine stands (Dickson 1978), probably due to their greater vegetative structural diversity. There are also a high density and a large variety of birds along forest edge (Strelke and Dickson 1980). Retention of strips of mature vegetation along permanent and intermittent streams in clearcuts has been recommended for deer, wild turkeys *Meleagris gallopavo*, squirrels, and song birds (Dickson and Huntley 1987).

There have been too few quantitative data on relationships of SZ to wildlife populations to enable wildlife managers to justify the retention of SZ in land-use plans on a biological or economical basis. Relationships between SZ presence, width, and vegetative composition and wildlife abundance have not been known. Personnel from the U. S. Forest Service's Wildlife Habitat Laboratory at Nacogdoches, Texas are conducting research to help understand these relationships by assessing the impact of extent and vegetative composition of SZ on the vertebrate wildlife community. The intent of this paper is to provide a background on the nature of SZ in the forests in the southern USA, detail the approach and techniques of our research, and present recent results on SZ width and animal relative abundance for squirrels, small mammals, and reptiles and amphibians.

Study Areas and Methods

The studies for which data are reported here were conducted on nine young pine plantations in three locations in east Texas that were 2 to 5 years old and 49 to 121 hectares in size. Selection of the nine areas was based on similarity of topography, soils, vegetation, and surrounding land use. All areas were previously vegetated by second growth pine-hardwoods, had been recently clearcut, mechanically prepared, planted to loblolly pines *Pinus taeda*, and traversed by SZ. Mature pines had been harvested from some of the SZ. All plantations were on upland sites, and SZ were along first- and second-order intermittent streams. Pines were generally 0.5 to 2.0 m high. The young plantations were dominated by hardwoods, pines, and other woody and herbaceous vegetation. Oak *Quercus* spp. and sweetgum *Liquidambar styraciflua* sprouts, American beautyberry *Callicarpa americana*, blackberry and dewberry *Rubus* spp., and sumac *Rhus* spp. were abundant. Dominant overstory trees in SZ included sweetgum, white oak *Q. alba*, southern red oak *Q. falcata*, blackgum *Nyssa sylvatica*, and loblolly pine.

Assigned treatments were SZ of three widths: narrow (< 25 m), medium (30-40 m), and wide (> 50 m). Narrow SZ were characterized by a narrow strip of trees averaging 16 m in width, a narrow tree canopy, sunlight into the SZ from the sides, little shading, a dense growth of herbaceous and woody vegetation, and often residual logging slash. Medium zones were wide enough (mean width = 36 m) generally to provide a shaded understory, limited ground level vegetation, and a leaf litter ground cover. The widest SZ were 52 to 93 m in mean width, providing the largest mature habitat blocks, mostly continuous canopy cover, a shaded understory, and leaf litter ground cover.

A replication of each treatment was applied in each of three different locations. In each location there were three pine plantations (study sites) traversed by a narrow, medium, and a wide SZ. All three locations were surveyed for squirrels, and two locations were censused for small mammals, and reptiles and amphibians. Four sample transects (200 m each) were established in each of the nine study sites — two in each SZ and two in each adjoining pine plantation. Understory, midstory, and overstory vegetation was sampled from four points on each transect. Also, hard mast was sampled by visual estimates in tree canopies that were corrected by samples of fallen fruit in barrels each fall.

Relative squirrel abundance was estimated with time-area counts (Goodrum 1940) on two locations in 1984 and on all three locations in 1985 from observation points at least 100 m apart in each SZ. Observation time at each point was 20 min, as recommended by Bouffard and Hein (1978). All counts were completed between 0700 and 1030 hours in the latter half of September, before squirrel hunting season. Four observation points were established in each SZ. Each count-morning, each of three people counted squirrels in the narrow, medium, and wide SZ at each location, and each person counted squirrels one time at all points in all SZ each year. Number of 20-min counts per treatment = 5 locations (2 in 1984, 3 in 1985) × 4 points for each SZ × 3 counters = 60. One additional count was taken in each adjacent plantation near the SZ edge to determine squirrel use of plantations. The number of squirrels seen during these 4 h of observation for each SZ was used as an index of squirrel relative abundance. Squirrel densities based on average detection distances were not calculated.

Squirrel leaf nests were counted in January and February of 1985 for another index of squirrel abundance. In each SZ, all nests that occurred in two 200- by 80-m transects and that appeared to have been constructed in the prior year were counted.

Small mammals, excluding squirrels, were sampled along the transects in the SZ in two locations (six study sites). Thirteen aluminum Sherman live traps were placed 12.5 m apart on each of the 12 transects. Trapping was conducted on 4 consecutive nights of 2 consecutive weeks (8 nights) during February and March in 1986 and again in 1987 (52 traps per treatment × 8 nights × 2 years = 832 trap nights). Traps were baited with oatmeal each morning and checked the following morning.

Amphibians and reptiles were surveyed using standard visual counts, systematic drift fences with funnel traps, and artificial shelters along SZ transects in two locations (six study sites) in 1984 and 1985. Each study site was surveyed six times from April to June each year.

Other vertebrates are being sampled by various means. Deer relative abundance was estimated using track plots in SZ and plantations during the fall and spring, and radio instrumented deer are currently being tracked to ascertain seasonal SZ use. Scent stations baited with bobcat *Felis rufus* urine and fish oil are used to survey furbearers each fall and winter. Birds have been censused from transects during winter and the breeding season. Wild turkey seasonal use of SZ is being determined in a companion study by radio telemetry. Summary data for squirrels, small mammals, and reptiles and amphibians are presented here; other studies continue.

Results and Discussion

In the time-area counts, squirrels were observed regularly in wide, very rarely in medium, and never in narrow SZ (Table 1). In both years, a total of 24 squirrels were observed in wide, one in medium, and none in narrow SZ (Dickson and Huntley 1987). Leaf nest density was also much greater in the wide SZ, with 55 nests counted in wide, 7 in medium, and 1 in narrow SZ. Time-area counts and leaf nest densities indicated that squirrels were permanent residents in only the three wide SZ, which averaged 93, 79, and 52 m in width. The 79-m SZ had the greatest squirrel abundance in both years and the greatest density of leaf nests. This SZ also had large American beech *Fagus grandifolia* and loblolly pine trees, which the 93-m SZ generally lacked. These were prime sources of food and cavity and leaf nest sites and may have accounted for the higher squirrel numbers in the wider SZ. Apparently, the minimum width of SZ that will maintain squirrel populations is about 50 m. Fewer squirrels were observed in the 52-m SZ than in the other two wider SZ. Streamside zones narrower than about 50 m do not appear capable of supporting permanent resident populations of squirrels. We observed only light squirrel use in the medium SZ of 30 to 40 m width. Only one squirrel was detected in medium SZ during the survey, only seven nests in 1,200 m of SZ were found, and signs of squirrel feeding were sparse. No squirrels, only one nest, and no signs of squirrel feeding were observed in narrow SZ. Only three squirrels were seen from the plantation edge points; all were in SZ. No squirrels were detected in the 2- to 4-year-old plantations.

Table 1.—Relative animal abundances in streamside zones in pine plantations.

	Streamside zone width		
Animal group	Narrow	Medium	Wide
Squirrels observed per hour	0	0.1	1.2
Squirrel leaf nests per 100 m of SZ	0.1	0.6	4.6
Small mammals captured per 100 trap nights	20	10	8
Reptiles and amphibians detected per transect survey	7	21	25

Both fox squirrels *Sciurus niger* and gray squirrels *S. carolinensis* were observed from the time-area counts in SZ. Gray squirrels were more common in two of the wide areas, but fox squirrels were predominant in the other.

Small mammal captures per treatment were approximately normally distributed and were tested for differences by ANOVA and Duncan's Multiple Range Test. Significantly more ($P < 0.05$) small mammals were captured in the narrow SZ (165) than in the medium (82) or wide (65) zones (Dickson and Williamson, 1988). Fulvous harvest mice *Reithrodontomys fulvescens* were much more abundant in the thick, brushy narrow riparian zones (73) than the medium (4) or wide (3) zones with shaded, sparse understories. *Peromyscus* spp. were abundant in all zones. Species of lesser abundance were the cotton rat, eastern harvest mouse *Reithrodontomys humulis*, golden mouse *Ochrotomys nuttalli*, wood rat *Neotoma floridana*, and short-tailed shrew *Blarina brevicauda*. There were too few data for these species to determine SZ relationships.

Some 1,628 amphibians and reptiles of 31 species were recorded in that phase of the study (D. C. Rudolph and J. G. Dickson, unpublished results). Data analysis revealed that medium and wide SZ supported many more amphibians and reptiles than narrow zones. Apparently, this difference was habitat related. The medium and wide SZ had a distinct overstory, a shaded understory, and an accumulation of ground litter. The narrow SZ had little overstory and a dense understory.

In conclusion, SZ enhance wildlife habitat for a variety of vertebrate wildlife, but each animal group relates differently to SZ width. Squirrels require wide zones for minimal habitat requirements. Zones less than about 50 m wide do not appear to be capable of supporting year-round squirrel populations. Streamside zones wide enough for a closed tree canopy, shaded understory, and a leaf litter ground cover provide adequate habitat for southern reptiles and amphibians. Small mammals are most numerous in thick, brushy narrow zones with remnant logging debris, but similar habitat is abundant on adjacent upland young plantations. Some small mammal species associated with mature stands, such as the short-tailed shrew, may require medium to wide zones.

Streamside zones are particularly important for wildlife considering wildlife community habitat associations and overall land-use changes. In the southern USA, some mature pine-hardwood stands are being harvested and planted to pine plantations. In 1985, area in pine plantation had increased to 8.5 million hectares and is projected to more than double by the year 2030 (U. S. Forest Service 1988). Recently, oak-gum-cypress, or bottomland hardwood, forests have been drastically reduced, converted to row crops, pasture, and reservoirs (Dickson, 1988). The reduction of these mesic to hydric mature forests diminish habitat for wildlife species associated with them. Streamside zones are strips of mature mesic forests that can provide limited mature habitat and may be positive for wildlife as travel and genetic corridors. These zones may be critical habitat for obligate mature habitat species; species such as the short-tailed shrew or pileated woodpecker could benefit. Streamside zones also have positive benefits for many game species of high profile that are supported by user groups. For example, extensive stand conversion of mature pine-hardwood stands to pine plantations seriously reduces habitat suitability for wild turkeys. But wild turkeys can be maintained in areas where there are SZ and some mature stands.

Streamside zones also can help maintain biological diversity and could provide barriers for insect pests in monoculture stands, such as the southern pine beetle *Dendroctonus frontalis*, but quantitative data are needed for decisions to manage SZ. Substantial research applying a systems approach is merited to assess and define hydrologic, vegetative, and faunal relationships over the long term.

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Habitat Use by Beaver Along the Big Sioux River in Eastern South Dakota

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Abstract.—Habitat use by beavers *Castor canadensis* was investigated during 1985 and 1986 in grazed and ungrazed areas along the Big Sioux River in eastern South Dakota. Almost half (48%) of the trees in ungrazed areas were small (diameter at breast height or DBH$<$ 7.5 cm), but a majority (58%) of the trees in grazed areas had large diameters (DBH$>$ 30 cm). Beaver activity was evident on 280 of 2,369 (11.8%) trees (DBH$>$ 2.5 cm) and 756 of 7,794 (9.7%) stems (DBH$\leq$ 2.5 cm) sampled. A greater proportion ($P \leq 0.01$) of trees were cut by beavers in ungrazed than in grazed areas. Beaver did not select tree species for cutting according to availability ($P \leq 0.01$). Trees cut by beaver were significantly smaller in diameter ($P \leq 0.01$) than uncut trees. Mean distance from water of cut trees was less ($P \leq 0.01$) than for uncut trees. Over half (52%) of the trees damaged by beaver either resprouted or remained alive and standing.

It is broadly accepted that riparian habitat is important in reducing soil erosion, stabilizing river banks, and providing habitat for wildlife. In much of the northern great plains, riparian habitat contains the only naturally occurring trees. In many areas, agricultural activities have degraded these natural forests, at the same time, planted tree claims and shelterbelts have generally declined. Therefore, a prime concern of land managers in South Dakota is the preservation of existing riparian habitat. Along the Big Sioux River in eastern South Dakota, extensive areas of habitat have been degraded or lost due to livestock grazing (Smith and Flake 1983).

Grazing can have negative effects on beaver *Castor canadensis* populations as well as on riparian habitat. After cattle are introduced into riparian habitat, there is often a gradual decline in stands of willow *Salix* spp. because beaver harvest mature woody plants and cattle harvest or trample new regeneration (Munther 1981). Beavers alter riparian habitat by cutting trees and damming streams. These activities slow water currents and create ponds, which can benefit waterfowl (Beard 1953), mammals (Yeager and Rutherford 1957), warmwater fish (Hanson and Campbell 1963), and trout (Gard 1961; Rutherford 1964). The same activities cause beavers to be viewed as pests by forestry personnel and landowners (Miller 1985). It has been suggested that beaver may be adding to the loss of riparian habitat along the Big Sioux River because of their natural activity of cutting trees.

Objectives of this study were to quantify the effects of livestock grazing on riparian habitat, compare habitat use by beaver in ungrazed areas with adjacent areas grazed by cattle, and determine if beaver activity is accelerating the destruction of habitat along the Big Sioux River.

Study Area

The study area was located in Brookings and Moody counties in east-central South Dakota along approximately 23 km of the Big Sioux River, the primary drainage of the Coteau des Prairie. The Big Sioux River originates in Grant county, South Dakota and flows in a southerly direction to enter the Missouri River at Sioux City, Iowa. The river's floodplain is usually inundated each spring by runoff from a large watershed area. Width of the river channel within the study area varies from 15 to 40 m and water depth ranges from 0.3 to 1.7 m. The river bed consists mainly of shifting sand and small gravel, but silt beds are found in quiet backwaters.

The Big Sioux River supports a marginal game fish population consisting of walleye *Stizostedion vitreum* and northern pike *Esox lucius*. The predominant fish species present are bullhead *Ictalurus* spp., channel catfish *I. punctatus*, and carp *Cyprinus carpio*.

Grazing of livestock and cultivation of small grain and corn are the primary agricultural land uses along the Big Sioux River. Grazed areas are characterized by a few scattered large trees with no regeneration and little understory. Ungrazed areas have thick understory growth and an abundance of small trees interspersed with large trees.

Methods

From May to August 1986, the study area was surveyed in an effort to quantify existing riparian habitat and to estimate beaver use of riparian tree and shrub species. Sample plots were defined as variable-length strip transects 3-m wide with their respective lengths being the distance in meters from the shoreline to the edge of wooded habitat farthest from the river. Plots were randomly located along the main river channel, as well as along all backwaters in old river channels.

To survey a plot, I walked toward a fixed point while holding a 3-m rod at its midpoint. All woody plants contacted by the rod were considered to be in the plot and were listed by species. Woody trees and shrubs encountered were grouped according to diameter at breast height (DBH), as stems (DBH$\leq$ 2.5 cm) or trees (DBH$>$ 2.5 cm). Trees and stems that were alive or had been damaged or killed by beaver were included, but trees killed by disease or flooding were omitted. Actual density (AD = number of trees of species A/hectare), and relative density (RD = number of trees of species A $\times$ 100/total number of trees), were calculated for all trees and by tree species for the entire riparian community.

Those trees or stems that had been damaged by beaver were separated by extent and type of cutting: (1) trees felled recently (fresh cuts), (2) trees felled in previous years (old cuts), (3) alive and standing but damaged, and (4) cut with resprouting. Fresh cuts were defined as cuts occurring in the post-winter period of the current year as determined by the observer. Old cuts were defined as those trees that were cut by beaver in a previous year and did not survive due to the damage. The third category included trees that had suffered obvious beaver damage but were not killed by this activity. Examples were large trees that had been cut only partially through the trunk and trees that had been stripped of bark. Trees or stems that had been cut by beaver often exhibited regrowth around the stump, and those encountered in the sample were grouped as cut with resprouts.

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Relative cuts (Cr = number of trees of species A cut × 100/total trees cut) were calculated for all tree species. Chi square analysis was used to test if beaver selected tree species in proportion to their availability in the study area. If there were significant differences, confidence intervals were constructed around the proportion of observed use of the tree species to determine selection or avoidance (Neu et al. 1974; Byers and Steinhorst 1984). A chi square test was also used to test if beaver were cutting trees in equal proportions in both land use categories. Analysis of variance was used to determine if there was a difference in DBH and distance from water of all trees between land use categories and to determine size of trees and distance from water of trees selected for cutting by beaver.

Results

Habitat Conditions

A total of 509 plots, which had a combined distance of 24.8 km and encompassed an area of 7.42 hectares, was sampled. In the study area, 55% of the forest was not grazed, 39% was grazed, and 6% was farmed. Eleven species of trees were encountered (Table 1). Sugar maple (*Acer saccharinum*) and russian olive (*Elaeagnus angustifolia*) are not considered further in this paper due to small sample size. Because of the small amount of area farmed, we will limit our discussion in this paper to ungrazed and grazed land use categories.

Grazing activity has changed the forest community structure. Grazed areas had a low AD (173 trees/hectare) and were characterized by scattered large trees with few young trees present. In ungrazed areas, AD was high (452 trees/hectare) with an abundance of small trees interspersed with large trees. All species except peachleaf willow (*Salix amygdaloides*) had a higher AD in ungrazed areas than in grazed areas. Green ash (*Fraxinus pennsylvanica*), peachleaf willow, and hackberry (*Celtis occidentalis*) had a higher RD in grazed areas than in ungrazed areas. All other species had a greater RD in ungrazed areas than in grazed areas (Table 2).

Analysis of variance indicated that there was a significant difference in DBH between categories of land use ($P \leq 0.01$). Analysis of least square means showed a significant difference ($P \leq 0.01$) in DBH between grazed areas (37.7 cm) and ungrazed areas (20.4 cm). In ungrazed areas almost half (48%) of the trees had a DBH under 7.5 cm, while a majority (58%) of the trees in grazed areas had a DBH greater than 30 cm (Table 3). Sandbar willow *S. exigua* was the most common species in the stem category, comprising 90% of all stems encountered. Stems were abundant in ungrazed areas, but few stems were located in grazed areas.

Beaver Cuts

Beaver activity was evident on 280 (11.8%) of 2,369 trees and 756 (9.7%) of 7,794 stems sampled. Ungrazed areas (13.8%) had a significantly higher percentage ($P \leq 0.01$) of trees cut than grazed areas (5.2%). Number of trees cut/hectare was also higher in ungrazed (62.0) areas than in grazed (9.1) areas. Green ash was the most utilized tree species, comprising nearly 69% of those trees cut by beaver. Chi square analysis (Table 4) indicated that beaver did not select trees for cutting according to their availability ($P \leq 0.01$). Green ash was selected for, but both boxelder (*Acer negundo*) and hawthorn (*Crataegus mollis*) were selected against (Table 4).

Analysis of variance showed a significant difference ($P \leq 0.01$) in mean DBH between trees that were cut (13.7 cm)

Table 1.—Species, numbers, and percentages of trees sampled along the Big Sioux River in eastern South Dakota in three land use categories: ungrazed (NG), grazed (GR), and farmed for crop production (F).

Species	Land use category NG	GR	F	Number of trees	Percent
Green ash *Fraxinus pennsylvanica*	712	270	8	990	41.1
Boxelder *Acer negundo*	453	69	13	535	22.2
American elm *Ulmus americana*	196	55	14	265	11.0
Peachleaf willow *Salix amygdaloides*	132	110	3	245	10.2
Hawthorn *Crataegus mollis*	207	24	0	231	9.6
Tartarian honeysuckle *Lonicera tatarica*	54	12	0	66	2.7
Hackberry *Celtis occidentalis*	26	9	0	35	1.5
American plum *Prunus americana*	23	3	3	29	1.2
Cottonwood *Populus deltoides*	10	4	0	14	0.5
Sugar maple *Acer saccharinum*	3	1	0	4	0.0
Russian olive *Elaeagnus angustifolia*	2	0	0	2	0.0
Total	1,818	557	41	2,416	100.0

Table 2.—Actual density (AD = trees/hectare) and relative density (RD = trees of species A × 100/total trees) of nine tree species along the Big Sioux River of eastern South Dakota by land use category.

Species	Ungrazed AD (RD)	Grazed AD (RD)
Green ash	178 (40)	84 (49)
Boxelder	113 (26)	21 (12)
American elm	49 (11)	17 (10)
Peachleaf willow	33 (7)	34 (20)
Hawthorn	51 (11)	8 (5)
Tartarian honeysuckle	13 (3)	4 (2)
Hackberry	6 (1)	3 (2)
American plum	6 (1)	1 (0)
Cottonwood	3 (0)	1 (0)
Total	452 (100)	173 (100)

Table 3.—Size-class distribution of nine tree species based on diameter at breast height (DBH) in grazed and ungrazed areas along the Big Sioux River in eastern South Dakota in 1986.

DBH (cm)	Grazed *N* (%)	Ungrazed *N* (%)
2.5-7.5	90 (16)	880 (48)
7.6-15.0	39 (7)	251 (14)
15.1-30.0	107 (19)	257 (14)
30.1-50.0	175 (32)	224 (12)
50.1 and over	145 (26)	201 (11)
Total	556 (100)	1,813 (100)

and those uncut (25.8 cm) by beaver. For all species combined, beaver selected trees of smaller diameter to cut (Figure 1). The mean DBH of cut trees was less than that of uncut trees for all species except hawthorn and significantly lower ($P \leq 0.01$) for green ash, boxelder, and peachleaf willow (Table 5). The mean DBH (11.8 cm) of cut trees in ungrazed areas was significantly less ($P \leq 0.01$) than the mean DBH (21.7 cm) for uncut trees. The mean DBH (31.0 cm) of trees cut by beaver in grazed areas was smaller, but not significantly so ($P = 0.14$) than the mean DBH (38.7 cm) of uncut trees. Trees cut by beaver were significantly larger ($P \leq 0.01$) in grazed areas (DBH = 31.0 cm) than ungrazed areas (DBH = 11.8 cm).

Table 5.—Comparison of least square means of diameter at breast height (DBH) and distance from water of nine tree species cut by beaver along the Big Sioux River of eastern South Dakota.

	Mean DBH (cm)		Mean distance from water (m)	
Species	Uncut	Cut	Uncut	Cut
Green ash	30.3	14.2^a	25.7	6.8^a
Boxelder	22.8	9.8^b	21.4	6.0^a
Cottonwood	88.5	0	38.8	0
Peachleaf willow	54.3	18.3^a	21.7	6.4^a
American plum	5.3	0	23.9	0
Tartarian honeysuckle	3.0	2.5	23.6	1.0
American elm	9.5	7.5	27.9	7.7^a
Hawthorn	8.3	9.7	36.4	13.3^a
Hackberry	20.5	15.3	20.7	2.8

[a] Significant at $P \leq 0.01$

[b] Significant at $P \leq 0.05$

Table 4.—Tree species selection or avoidance (95% confidence interval) by beaver along the Big Sioux River in eastern South Dakota. Incidences of trees cut among tree species differed significantly (Chi square test; 8 d.f.; $P \leq 0.01$).

Tree species	Proportion of trees available (*N*)	Proportion of trees cut (*N*)	95% CI on proportion observed
Green ash	0.41 (990)	0.689^s (187)	$.618 < P_1 < .760$
Peachleaf willow	0.10 (245)	0.105 (30)	$.058 < P_2 < .152$
American elm	0.11 (265)	0.091 (26)	$.047 < P_3 < .135$
Boxelder	0.22 (535)	0.062^a (18)	$.025 < P_4 < .099$
Hawthorn	0.10 (231)	0.035^a (10)	$.006 < P_5 < .064$
Hackberry	0.01 (35)	0.011 (4)	$.004 < P_6 < .016$
American Plum	0.01 (29)	0.004 (1)	$.000 < P_7 < .010$
Cottonwood	0.01 (14)	0.000 (0)	
Tartarian honeysuckle	0.03 (66)	0.000 (0)	

[a] avoidance (proportion of available trees > upper confidence limit);

[s] selection (proportion of available trees < lower confidence limit).

Beavers preferred trees close to water for cutting (Figure 2). There was a significant difference ($P \leq 0.01$) between the mean distance from water of uncut trees (26.6 m) and cut trees (3.3 m) in grazed areas and between uncut trees (25.6 m) and cut trees in ungrazed areas (7.5 m). There was no significant difference ($P = 0.29$) between the mean distance from water of trees cut in grazed areas (3.3 m) and those cut in ungrazed areas (7.5 m). Of the 286 trees damaged by beaver, 138 (48%) were killed and 148 (52%) were not killed by cutting activity.

Figure 1.—Number and percentages of trees cut by beaver based on diameter at breast height (DBH) along the Big Sioux River of eastern South Dakota.

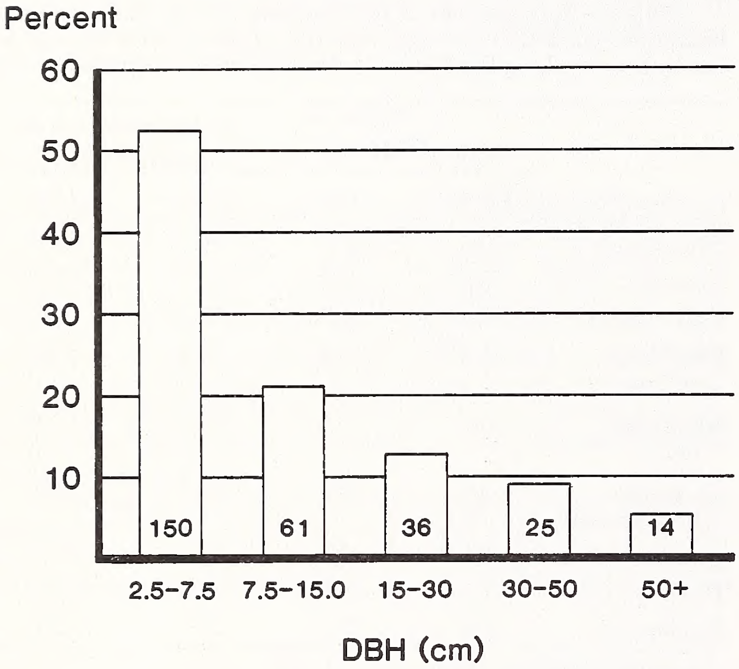
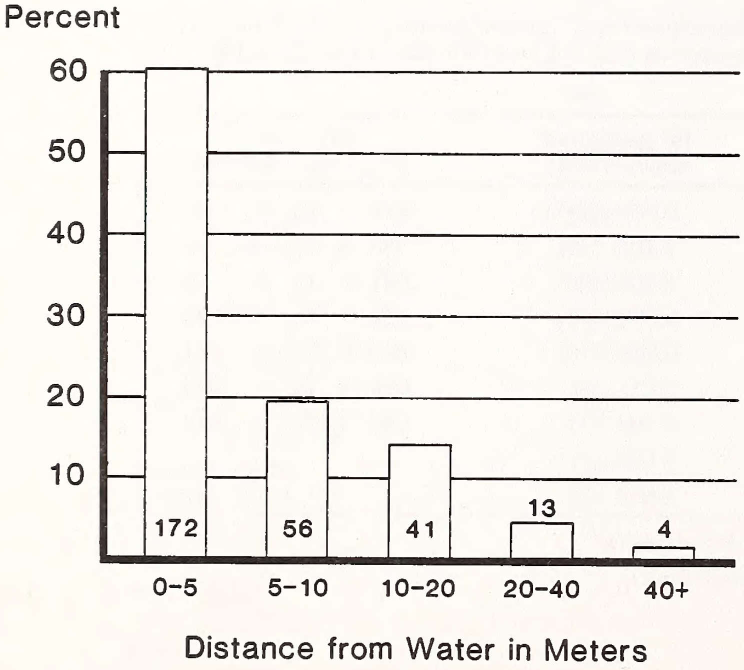


Figure 2.—Number and percentages of trees cut by beaver based on distance of the tree from water along the Big Sioux River of eastern South Dakota.



Discussion

Although detrimental effects of beaver activity on planted hardwood seedlings have been documented in southeastern USA (Krinard and Johnson 1981), negative effects of beaver on riparian habitat are difficult to assess and often become a matter of opinion. In marginal trout waters in the east and midwest USA, beaver activity may be detrimental to trout (Knudsen 1962).

However, along most natural riverine systems, beaver activity is viewed as beneficial. Beaver are being reintroduced into high gradient streams in western states in an effort to improve habitat (Brayton 1984). Beneficial effects on fisheries in warm-water streams include slowed currents and increased stream fertility (Hanson and Campbell 1963). In the Big Sioux River, beaver activity had no obvious negative effects on the fisheries. Northern pike were observed frequently in beaver ponds, which provide excellent spawning habitat. The damming of small feeder streams creates productive ponds that provide important habitat for wildlife, especially waterfowl (Beard 1953; Henderson 1960; Knudsen 1962).

Livestock grazing, which has caused a dichotomy in habitat conditions along the Big Sioux River, can influence beaver activity (Munther 1981). Dieter (1987) found 27 (82%) of the 33 active beaver lodges along a portion of the Big Sioux River were located in ungrazed habitat, although only 40% of the study area was ungrazed. Areas unaltered by grazing have an abundance of small trees and stems of common species which are important to beaver populations (Novakowski 1967; Northcott 1971; Jenkins 1975; Pinkowski 1983). Grazed areas have a few large trees and almost no small trees or stems available for beaver use. Willow stems are an important food item for many beaver populations (Hammond 1943; Swenson and Knapp 1980). Livestock activity eliminates willow stems, causing beaver living adjacent to grazed areas to select alternate forage species.

Our study indicated that beaver activity occurring in ungrazed areas was positively related to availability of willow stems and to the higher density of small diameter, preferred tree species. Little beaver activity occurred in grazed areas and the limited cutting of large trees was probably due to availability rather than selection, as larger trees are generally cut only after small ones are used (Johnson 1983).

Small diameter trees near waterways were easier to cut and transport to lodge sites. In ungrazed areas, beaver had an abundance of trees available close to shore and could be selective, using small diameter trees first. Beaver living in grazed areas apparently used whatever size tree was available in close proximity to water. In most cases, beaver did not travel far from water to cut trees in either land use category.

Aspen *Populus tremuloides*, where present, is the preferred tree species of beaver (Hall 1960; Brenner 1962; Northcott 1971), but beavers often thrive where aspen are unavailable (Chabreck 1958; Nixon and Ely 1969). Use of green ash, the preferred tree species by beaver along the Big Sioux River, has been documented in other studies (Crawford et al. 1976; Pinkowski 1983).

Less than half of the trees cut by beaver along the river were killed. Some damaged trees remained alive and standing, but in many cases trunks of felled trees and stems resprouted, creating dense woody habitat. Hall (1960) showed that the quantity of willow removed at colony sites by beaver in California was almost totally replaced each year by rapid regrowth. In Oregon, willows used by beaver were able to maintain high growth rates and increased basal diameters similar to those of unused trees (Kindschy 1985). Krinard and Johnson (1981) reported that nearly all hardwoods cut by beaver in Mississippi sprouted back with little growth loss. Periodic fluctuations of beaver populations likely allow recovery of vigor in willow and other woody species (Kindschy 1985).

Beaver damage appears to have been greater in ungrazed areas where approximately 7% of the trees had been killed. However, the majority of tree cutting occurred on small diameter green ash trees, which regenerate rapidly. There was little damage to existing large trees, or any trees over 10 m from water. Damage incurred to trees in grazed habitat may be greater than in ungrazed habitat even though these areas are seldom used by beaver. While only about 3% of the trees were killed by beaver, almost all were large, mature trees and were not being replaced by regeneration due to effects of livestock.

Management Implications

Ungrazed areas were selected for and are most important to beaver populations. Rather than travel farther inland to cut large trees, beaver in grazed areas may move to ungrazed areas which have a greater abundance of stems and preferred trees. Ungrazed areas along the Big Sioux River are capable of sustaining a larger population of beaver than grazed areas and sufficient habitat exists to support beaver populations at current levels with few negative effects. The fact that beaver are being selective for trees by species, size, and distance from water indicates that the habitat is capable of supporting the current population, as a population running short of resources could not afford to be as selective.

Selection of ungrazed habitat by beaver reflects habitat quality. A return of suitable ungrazed habitat would help to distribute the existing beaver population over a greater area. Establishment of areas that will remain free of livestock grazing would benefit beaver populations. Beaver only influence areas of forest near the river, but cattle grazing affects the forest from streamside to its outer edge. Many species of wildlife would benefit from the increased habitat and topsoil erosion would be curbed.

We conclude that natural and prolonged use of habitat by beaver was not accelerating the reduction, deterioration, or loss of riparian tree species along the river. Few, if any trees were cut in grazed areas. In ungrazed areas, beaver activity was not suppressing regeneration. Other factors, especially continual cropping and trampling of regrowth by livestock during the growing season, were involved in limiting the riparian community. Livestock grazing should be restricted within a minimum of 100 m on either side of the river. This would allow for regeneration of areas presently in poor condition.

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Rehabilitating Depleted Riparian Areas Using Channel Structures

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Abstract.—Abusive land use activities have deteriorated valuable riparian areas in the southwestern USA. Loss of protective cover causes erosion which reduces soil moisture and channel stability that is necessary for maintaining riparian areas. Review of three rehabilitation projects in New Mexico and Colorado indicate that channel structures store sediment, stabilize channels, raise water tables, and enhance riparian vegetation. Rehabilitation planning should establish quantifiable treatment objectives and consider the need for riparian planting, continued watershed management, structural maintenance, and the effect of channel structures on channel dynamics.

Past abuse of wildlands throughout the southwestern USA by overgrazing, improper timber harvesting practices, road and trail construction, and other land use activities has destroyed valuable riparian habitat. Deterioration of these riparian plant communities occurred as follows. Livestock grazing and timber harvesting led to a loss of protective ground cover. When removal was severe, infiltration was reduced and overland flow increased. Excessive overland flow increased channel flows which resulted in channel enlargement and incision. Incising channels intercepted and drained existing water tables, reduced soil moisture, destroyed riparian plant communities, and reduced site productivity.

Early watershed managers recognized the need for programs aimed at rehabilitating misused and deteriorated watersheds (Forsling 1931; Leopold 1946). This awareness led to implementing watershed rehabilitation programs throughout the western USA. The objectives of these projects were to improve plant cover and reduce runoff and erosion by using revegetation techniques and/or structural treatments. Only recently have the benefits from these rehabilitation projects, aside from sediment and peak flow reductions, been recognized. Present day managers must be aware of the wide spectrum of rehabilitation benefits, including improvements in wildlife habitat, enhanced recreational opportunities, increased forage production, and improvements in visual quality. In addition to these benefits, managers should also recognize the potential for restoring or creating riparian areas.

Watershed rehabilitation treatments can be used for reversing the degradation pattern described earlier and can lead to the restoration of former or establishment of new riparian areas. However, before treatment, land managers need to clearly understand the reasons rehabilitation projects succeed and how they can determine realistic rehabilitation objectives. The objectives of this paper are to: (1) review three rehabilitation projects which enhanced or created riparian areas through the use of channel structures, (2) discuss the reasons for success, (3) present the benefits of these projects to riparian areas, and (4) discuss problems and concerns associated with using channel structures for enhancing riparian areas. These case studies are only a few examples of numerous watershed rehabilitation projects reported throughout the western USA that have benefited riparian areas (USGAO 1988). Our intention is that this information will make managers more aware of potential riparian benefits which can be derived from watershed rehabilitation projects.

Case Studies

Alkali Creek Watershed

The 260-hectare Alkali Creek watershed is on the White River National Forest and is located approximately 37 km south of the town of Silt, Colorado (Heede 1977). The watershed is located at elevations between 2,316 and 2,560 m in the Uinta Basin of the Colorado Plateau Province. Vegetation on the watershed is sagebrush*Artemisia* spp.-grassland typically found on the western slope of the Rocky Mountains in Colorado. Oak brush *Quercus* spp. occupies upper portions of north-facing slopes, while sagebrush and grass cover the valley bottoms, depressions, and southern aspects. Annual precipitation averages about 48 cm; about 40% occurs as rain between May and September and 60% as snow during the rest of the year. Valley bottom soils are sodic and contain high percentages of clay, reflecting the influence of sandstone and shale parent materials (Heede and DeBano 1984).

Livestock grazing began on the watershed in the 1870s and severely reduced ground cover. Loss of plant cover increased overland and channel flow and, as a result, initiated soil piping and gully formation. Extensive gully systems up to 15 m in depth were present throughout the watershed before rehabilitation was initiated. Streamflow was ephemeral before treatment, occurring only during snowmelt periods (Heede 1977). The area was fenced in 1958 and grazing was excluded between 1958 and 1966. Active gully treatment was started in 1961 with the objectives of (1) rehabilitating the depleted watershed by vegetative and engineering measures, (2) testing their combined effectiveness on restoration, and (3) developing new treatment approaches. Treatments consisted of constructing 132 check dams of various sizes and materials (Heede 1960, 1968b, 1970, 1976, 1980, 1982), planting vegetation along 579 m of waterways (Heede 1968a), and reseeding all disturbed areas.

The response of the watershed to gully treatment, revegetation, and grazing management was dramatic.

During the 12 project years, check dams accumulated 1,954 m^3 of sediment, gully depth was substantially reduced, and erosion rates were reduced by one-fifth (Heede 1977). In addition, the streamflow duration at Alkali Creek was increased. Before treatment, streamflow occurred only about 6 weeks during snowmelt periods. Seven years after treatment, streamflow was perennial at the watershed mouth but remained ephemeral in headwater areas (Heede and DeBano 1984).

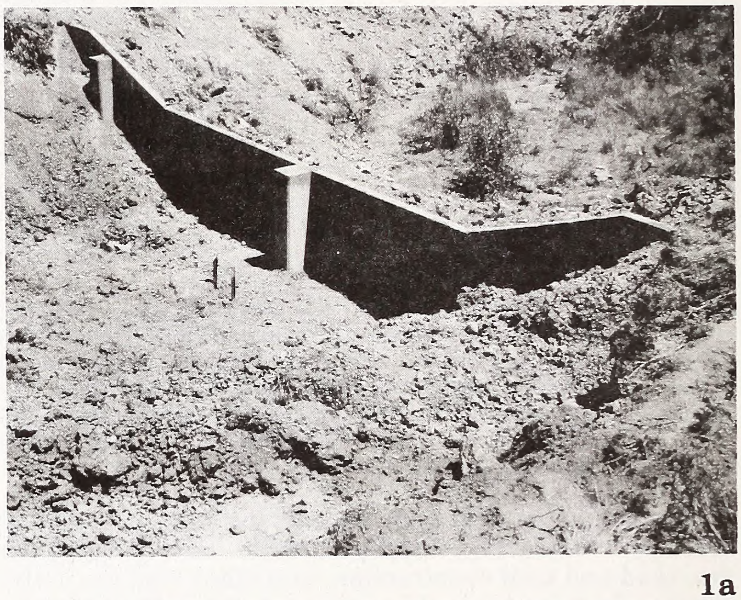
Streamflow duration was not extended long enough in headwater areas to allow riparian areas to become established, but increased grass production was apparent on sediment deposits behind check dams. In contrast, streamflow duration in main channels was increased so that riparian areas became established (Figure 1a,b,c). Streamflow duration was increased because water was stored in the deposited sediments. This storage provided for the "banking" of water in sediment deposited behind structures throughout the channel system. The slow release of this stored water from saturated sediments by unsaturated flow extended streamflow duration. This interpretation is consistent with results from lysimeter studies showing that saturated soils drain slowly by unsaturated flow and can sustain outflow for as long as 3 to 4 months after being charged with water (Hewlett and Hibbert 1963). Prolonged streamflow and increased soil moisture allowed sedges *Carex* spp. and willows *Salix* spp. to become established (Figure 1c). As additional sediment was stored, the channel became stabilized, and riparian vegetation and grass spread above check dams to the lower segments of the gully sideslopes. The size of gully check networks necessary for storing enough water to sustain perennial streamflow depends on local soil and climatic conditions and channel gradient. One hundred and thirty-two structures were sufficient to enhance riparian vegetation establishment by natural means under the prevailing climatic and topographic conditions at Alkali Creek (Heede and DeBano 1984).

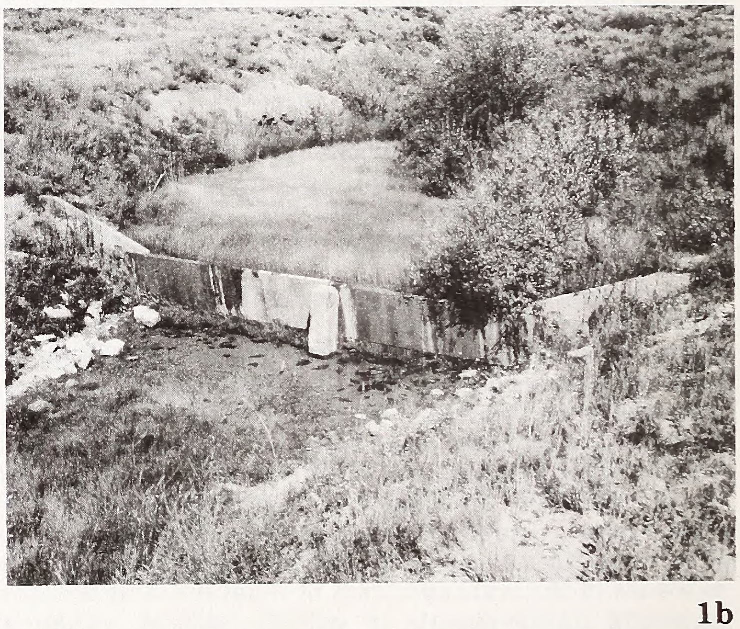
Silver City Watershed

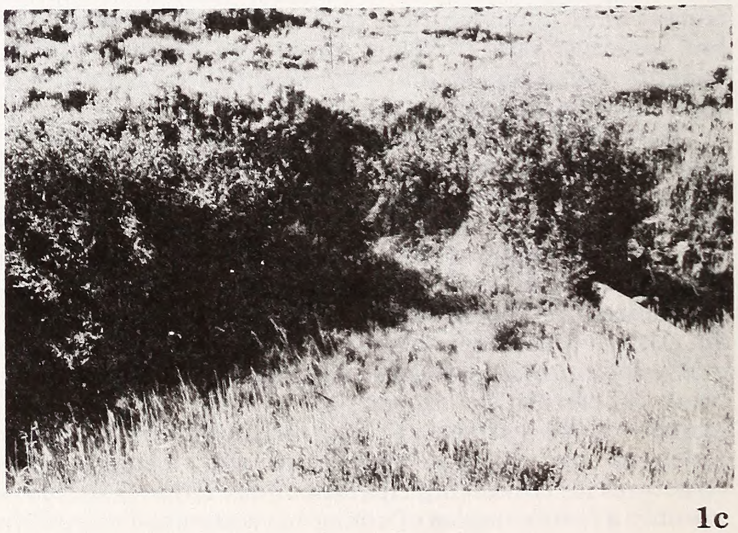
The 7,300-hectare Silver City watershed lies north to northwest of Silver City, New Mexico, at elevations between 1,890 and 2,134 m. Common rock types found on the watershed are acid igneous, conglomerates, andesites, rhyolites, shale, and sandstones. Soils derived from these rock types are shallow to deep, well drained, and have a moderate to high erosion hazard (Parham et al. 1983). Soils are easily eroded if the vegetative cover is lost. The watershed is characterized by four vegetative types: pinyon *Pinus* spp.-juniper *Juniperus* spp. woodland, ponderosa pine *Pinus ponderosa* forest, oak *Quercus* spp. shrub, and grassland with pinyon-juniper woodland being the dominant type (Columbus 1980). Average annual precipitation is about 41 cm, with almost 50% falling as rain during thunderstorms in July, August, and September.

Between 1870 and 1887, areas surrounding Silver City were extensively mined for gold, silver, and copper. Mining activities, home construction, and fuelwood demands resulted in abusive timber harvesting throughout the watershed. The area was also indiscriminately grazed by cattle, sheep, goats, mules, horses, and, in some places, swine. These land uses severely reduced watershed ground cover and infiltration and resulted in large stormflows which emptied downstream into Silver City. On 21 July 1895, a torrential rain on the watershed produced enough runoff to incise a 11-m deep ditch down Main Street (main

Figure 1.—The appearance of the site occupied by a larger channel at the mouth of Alkali Creek: (a) immediately after treatment in 1963, (b) in 1975, and (c) 20 years later in 1981. Figure 1c is an upstream view and structure can be seen at lower right corner of photo.







north-south thoroughfare) in Silver City. Later floods, climaxing in August 1903, lowered the ditch 17 m below the old street level and extended the ditch 24 km south of town.

In 1908, the northern and western portions of the watershed were reserved as part of the Gila National Forest. In 1924, the town of Silver City and the U. S. Department of Agriculture entered into a joint agreement restricting land use activities (e.g., grazing, timber harvesting, etc.) on the watershed. Grazing and fuelwood harvesting were excluded starting in 1927. The main objectives of the agreement were to implement a rehabilitation plan that would (1) restore and protect ground cover, (2) reduce runoff and flood hazards downstream to the town of Silver City, and (3) increase water infiltration and ground water storage, thereby enhancing Silver City's municipal water supply. With the elimination of abusive land use activities such as overgrazing and uncontrolled timber harvest, vegetative ground cover was reestablished. In addition to land use restrictions, channel structures were constructed to stabilize and restore channel systems and to improve ground water storage and flow regime downstream to Silver City.

Watershed rehabilitation was facilitated by a Civilian Conservation Corps (CCC) camp that was established on the watershed in 1933. Enrollees in the CCC program constructed 14,500 gully check dams, and planted over 84,000 cuttings, seedlings, and nursery stock to stabilize structures and channels. Most of the planting was done in drainages and included riparian species such as cottonwood *Populus* spp., willows and boxelder *Acer negundo*.

The response of the Silver City watershed to the exclusion of grazing, replanting, and channel treatment has been dramatic over the past 50 years. As a result of these treatments, hydrologic functioning of the watershed has been restored. Channel systems which were previously dominated by ephemeral flow are now perennial or provide seasonal flows of longer durations. Watershed management and treatment has restored ground cover, reduced flood hazards downstream to Silver City, and enhanced municipal water supplies.

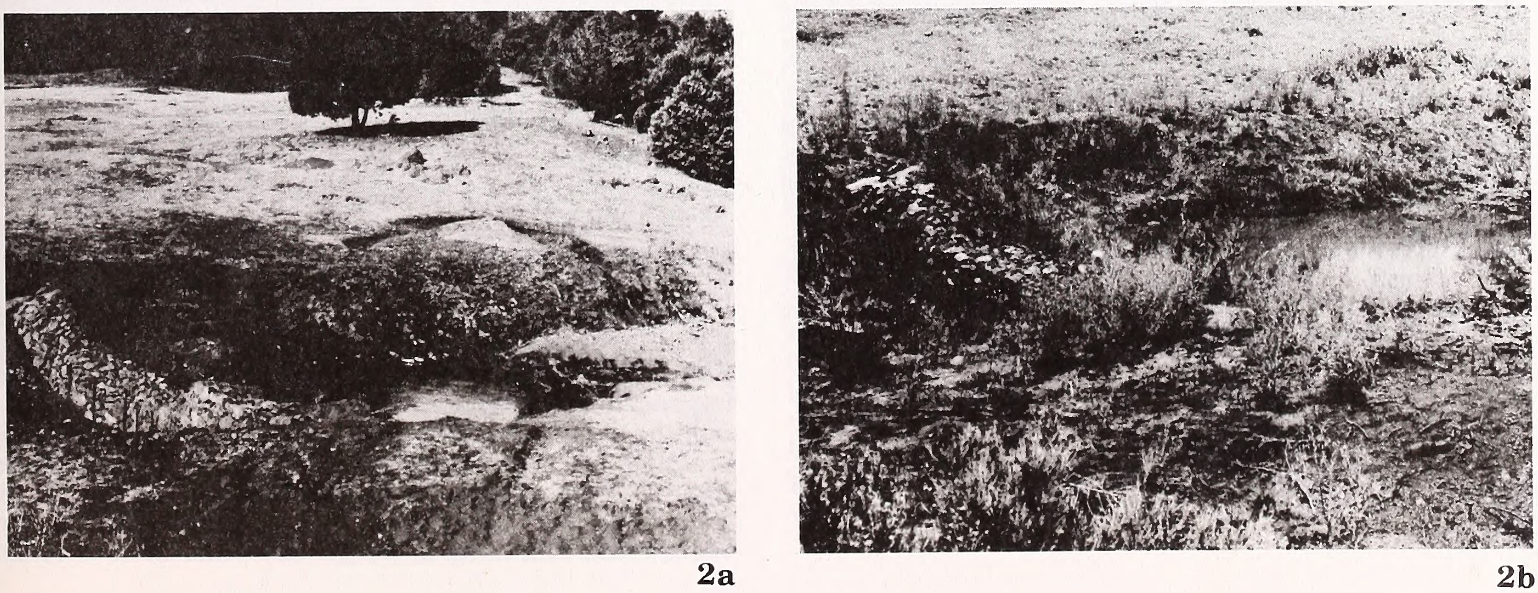
Check dams quickly filled with trapped sediment in the early 1930s and resulted in channel aggradation, improved ground water tables, and increased soil moisture conditions. Channel stability and reliable water supplies allowed planted riparian vegetation to grow rapidly and establish in areas above and below the channel structures. Although quantitative changes in streamflow have not been measured, channel stability and riparian rehabilitation have been documented by photo points throughout the watershed. Photo points were established in 1933 and were representative of conditions found on the watershed. Photos were taken of structures immediately after installation in 1933, later in 1936 and 1944, and finally 55 years later in 1988. Close examination of these photo sequences and field estimates allowed us to reconstruct the rehabilitation sequence of riparian areas currently present on the Silver City watershed.

A typical sequence of riparian plant establishment and growth is illustrated by changes at a photo point on an unnamed drainage. Photos were taken at this photo point in 1933, 1936, 1944, and 1988 (Figures 2a,b,c, and d, respectively). This structure was constructed in 1933 (Figure 2a). Within a few years, sediment had accumulated behind the structure and a sparse stand of willows and grasses were evident by 1936 (Figure 2b). The willows grew rapidly and a dense stand had become established by 1944 (Figure 2c). Field estimates in 1988 indicated that approximately 104 m^3 of sediment had accumulated behind the check dam by 1944.

Photo documentation and field observations in 1988 (Figure 2d) revealed some interesting changes in riparian areas. Willow thickets were dense but becoming decadent and contained few live stems. No additional cottonwood growth or sprouting has occurred since the original planting in the 1930s. These observations suggest that installing channel structures created a favorable environment for establishment and growth of planted species. It also appears that native willows would have invaded naturally. Conditions necessary for maintaining healthy willow stands and the regeneration of cottonwoods, however, seem to be absent.

Research on Fremont cottonwood *Populus fremontii* in Arizona has found that a special sequence of events is required for successful germination and establishment of this species in a natural environment (Fenner et al. 1984). Germination requires spring runoff to create the moist soil

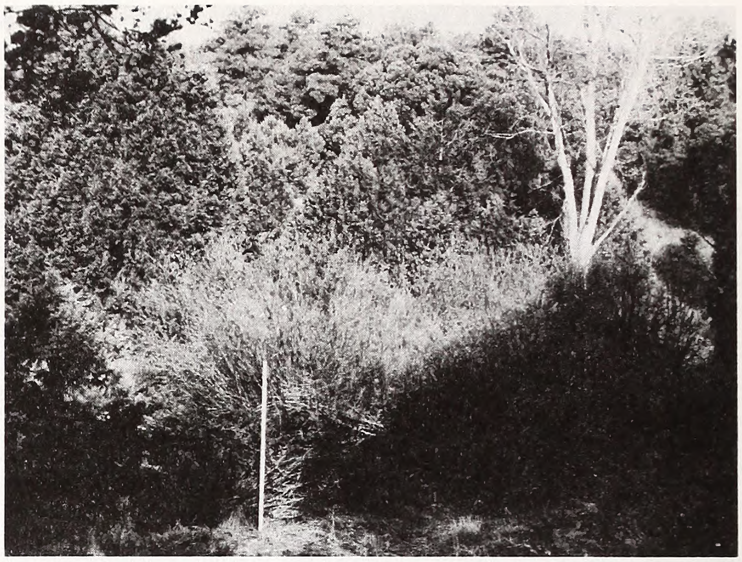
Figure 2.—Appearance of structure H-1 on the Silver City Watershed: (a) immediately after construction of the structure in 1933, and in (b) 1936, (c) 1944, and (d) 1988. Notice the rapid establishment and growth of willows between 1936 and 1944.



2a

2b

2c



2d

surfaces that must be present within 6 to 8 weeks following seed dispersal. Because only cottonwood trees that were planted during the rehabilitation project in 1933 were present suggests that the conditions necessary for regeneration are not, or never were, present.

It also appears that insufficient pruning had occurred to stimulate new growth and sprouting of willows and, therefore, the willow stands contained a high proportion of dead stems. Grazing or pruning of willow thickets may be required to prevent thickets from becoming decadent. Nearby thickets that had been grazed had fewer dead stems and appeared healthier than ungrazed thickets. Although the grazed thickets were healthier, they were also sparser. These observations indicate that grazing may be beneficial if it is regulated closely so as to prevent overgrazing.

High Clark Draw Watershed

The 111-hectare High Clark Draw rehabilitation project lies in the upper San Francisco River watershed about 10 km west of Luna, New Mexico, on the Apache National Forest (Hansen and Kiser 1988). Elevations range from 2,400 to 2,540 m, and annual precipitation ranges from 51 to 61 cm. Soils are derived from andesite, basaltic flows, and volcanic conglomerates. Soils from these parent materials are extremely sensitive to disturbance. The vegetation consists of ponderosa pine, pinyon-juniper, and grassland types.

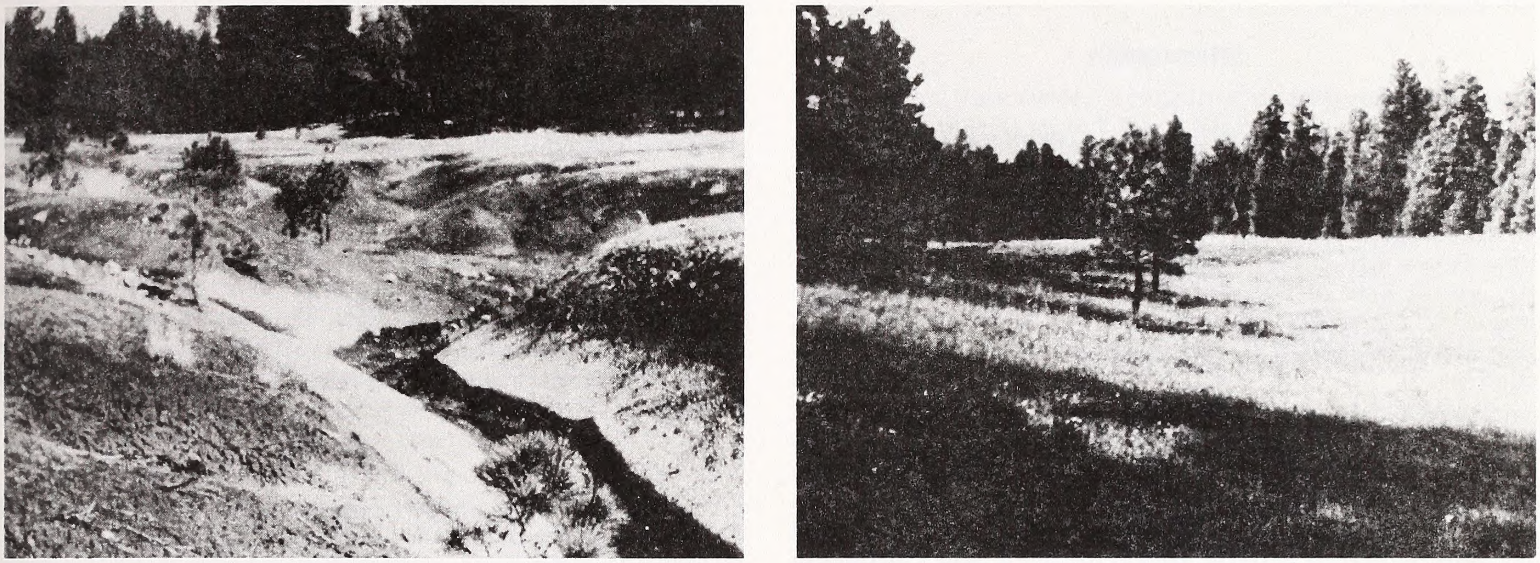
Dominant land uses since the beginning of the century were livestock grazing and timber and fuelwood harvesting. Land use activities, primarily grazing, depleted vegetative cover, increased overland flow, and increased channel flow and erosion. Increased channel flow resulted in channel incision and dewatering of the existing meadow. In 1956 and 1962, livestock numbers were reduced by 25% and 60%, respectively, to improve range and watershed condition. Reducing livestock numbers improved the ground cover by 1971, but the original hydrologic condition and site productivity could not be restored without structural treatment. Therefore, a rehabilitation program was developed in 1971 with the objectives of (1) restoring the ground water table, (2) improving forage production, (3) reducing runoff and erosion, and (4) reducing downstream delivery of sediment.

Treatment in 1972 consisted of constructing four earthen gully structures (USSCS 1976), contour trenching (Noble 1963) severely eroding lateral channels, channel shaping, installing road drainage, and seeding all disturbed areas. In 1978, six rock check dams were constructed in the headwaters of the watershed. Grazing was deferred for 2 years to enhance revegetation.

The combination of watershed treatment and grazing management on High Clark Draw improved streamflow regimes, increased soil moisture on the site, increased site productivity, improved wildlife habitat, increased recreational opportunities, and improved visual quality. The improvement can be seen by comparing photos taken in 1972 immediately before treatment (Figure 3a and 4a) with those taken in 1982, 10 years after treatment (Figure 3b and 4b). Channel shaping and revegetation successfully healed the gully above an earthen dam (Figure 3a and 3b). The construction of earthen gully plugs resulted in channel stabilization and aggradation, higher water tables, and increased soil moisture. The result of these treatments was the reestablishment of a wet meadow (Figure 4a and 4b). Riparian species such as sedges and rushes *Juncus* spp. dominate this meadow. Riparian dependent species such as cattails *Typha* spp. and buttercups *Potomogeton* spp. also became established in and around the open water areas created by the dams. Downstream riparian species such as narrowleaf cottonwood *Populus angustifolia* were enhanced by perennial flow.

An economic analysis (Hansen and Kiser 1988) evaluated the priced and nonpriced costs and outputs associated with the project. Evaluated outputs included forage production, sediment reduction, wildlife recreation visitor days, peak flow reductions, wildlife habitat improvement, and aesthetics. These outputs were evaluated using professional and model estimates. The analysis computed and compared relative rates of change for quantifiable variables. The economic analysis indicated that a positive benefit:cost ratio of 8:1 could be derived from treatment over a projected 50-year period. Estimated benefits included an increased livestock carrying capacity of 14 animal unit months per year after 10 years, a 87% reduction in annual sediment delivery in 15 years, a 63% reduction in peak flows after 15 years, and an increase of about 160 wildlife recreational visitor days per year after 10 years (Hansen and Kiser 1988). Estimates of the ground water table were not

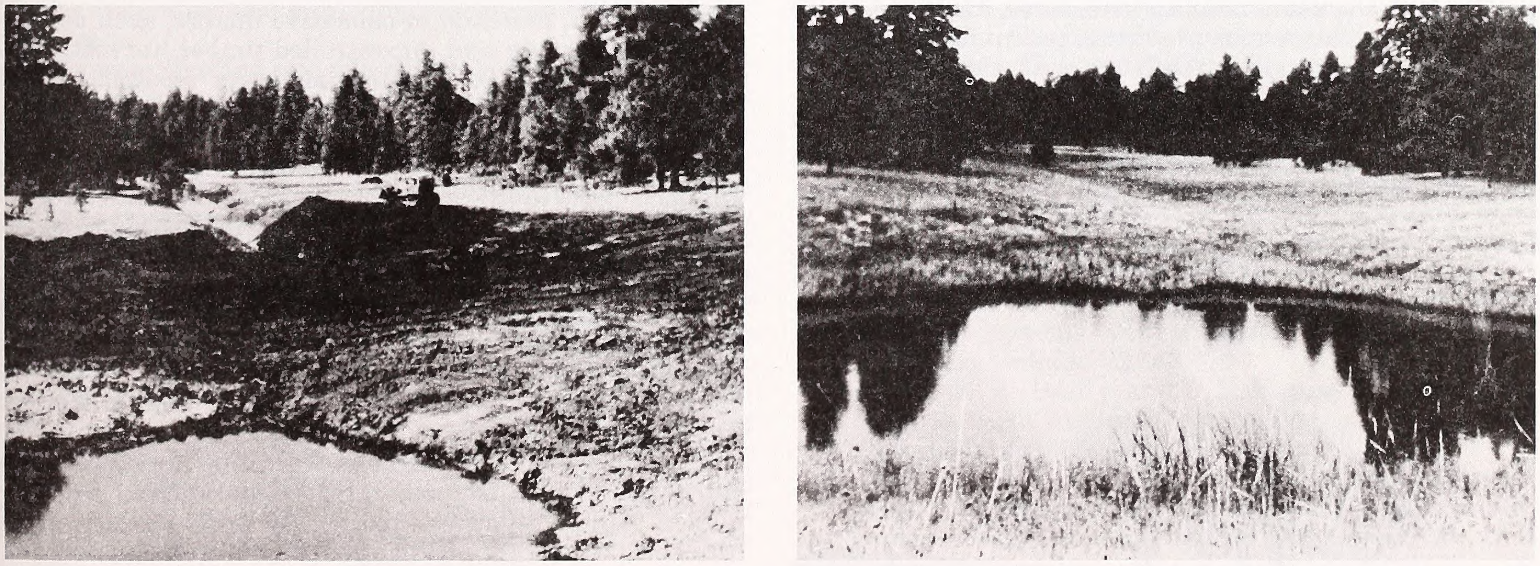
Figure 3.—A view upstream of an earthen dam on the High Clark Draw Rehabilitation Project: (a) April 1972 before treatment and (b) 10 years later in August 1982 showing the effect of sidesloping and gully shaping.



3a

3b

Figure 4.—A view upstream of an earthen dam on the High Clark Draw Rehabilitation Project: (a) April 1972 before treatment, and (b) 10 years later in August 1982 showing the effect of water impoundment, channel stability and sidesloping.



4a

4b

made, but growth of riparian areas clearly indicates that water tables were raised and soil moisture was improved.

In addition to achieving the objectives of restoring water tables, improving forage production and reducing runoff and erosion, the project reestablished riparian areas in a historical mountain meadow and downstream from the project area.

Discussion

Treatment Benefits

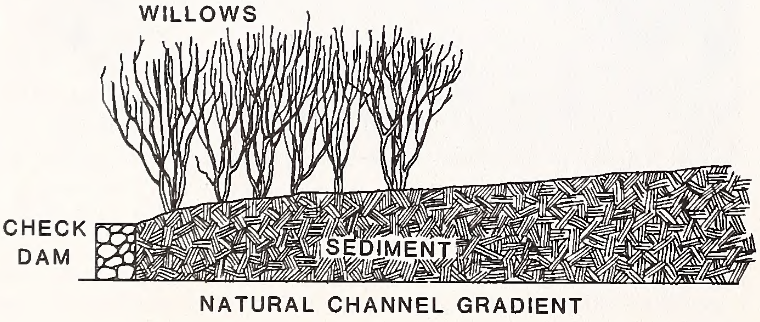
These three case studies indicate that several benefits, aside from erosion control, can result from structural treatment and watershed rehabilitation. Benefits include sediment storage, peak flow reduction, enhancement of base flows, water table recharge, increased site productivity, and a host of nonpriced benefits including enhancement of riparian areas, improved wildlife habitat, increased recreational opportunities, and improved aesthetics.

Constructing channel structures as part of a rehabilitation program not only reduces channel degradation but also provides a repository for sediment storage. Sediment storage enhances channel stability and raises ground water tables. Stored sediment and nearby channel banks become saturated during runoff periods and contribute directly to ground water tables or release stored water more slowly. This can result in either extended duration or perennial flows. Amount and duration of extended flow depends upon the quantity and physical nature (porosity, particle size, etc.) of the stored material. Storage of water and its slow release enhance moisture regimes and contribute to the reestablishment, maintenance, or creation of riparian areas.

The establishment of riparian vegetation on sediment deposits further stabilizes trapped sediments and may result in additional deposition that would not occur alone with channel structures (Figure 5). This occurs because trees and willows physically reduce flow velocities and capture suspended sediment. Willows are particularly effective because they produce a multi-stem barrier in the channel.

Through the use of channel structures, improved water storage and release can provide a technique for "water banking" on watersheds (DeBano et al. 1984). This technique could be used under varying watershed rehabilitation programs or with vegetative manipulations, such as brush to grass conversions, to improve flow regimes and to enhance or maintain riparian areas.

Figure 5.—Conceptual diagram showing storage of sediment resulting from structure and associated willow thickets.



Although watershed rehabilitation treatments can create or restore former riparian areas, treatment intensity, climate, and watershed size often limit the potential for enhancing riparian areas. Large numbers of channel structures were installed in the Silver City and Alkali Creek watersheds. On both these watersheds, riparian areas became established only near the mouth of the watershed. This probably occurred because streamflow duration was lengthened on drainages near the mouth of the watershed and because wider floodplains provided better environments for riparian plant establishment. Although structures in the upper part of the watershed collected and stored sediment, which improved plant growth, riparian species did not become established. Annual precipitation at Silver City and Alkali Creek was under 51 cm. In contrast, on the High Clark Draw Project, riparian species became established in areas where only a few structures were constructed. The annual precipitation at High Clark Draw (51 to 61 cm) offered a more favorable climate for riparian establishment and development, and therefore, fewer structures were required.

Concerns

Although watershed rehabilitation treatments and channel structures offer opportunities for enhancing riparian communities in the southwestern USA, there are some risks associated with their implementation (Schmidt 1987). Special attention must be paid to the development of treatment objectives, establishment of riparian species naturally or by planting, future maintenance, and changes in channel dynamics resulting from channel structures.

A systems approach should be used when planning watershed and riparian rehabilitation. This planning approach evaluates the conditions found in upland watersheds and channel systems and develops treatment measures which will accomplish a wide range of treatment objectives. Evaluation should consider cause and effect relationships, landscape and vegetative potentials, land use management, and future maintenance. Utilization of this approach in each case study was the primary reason for success. In each instance, removal of protective ground cover was determined to be the primary cause of watershed deterioration. Removal of causative factors, such as livestock overgrazing and uncontrolled timber harvest, were eliminated. Vegetative potentials were recognized and determined to be much higher than found before treatment. Treatment objectives were established to improve vegetative cover, reduce runoff and erosion, and improve site productivity. However, all three case studies failed to recognize the potential for restoring or establishing riparian areas as a viable treatment objective.

Land managers need to recognize the potential for restoring and establishing riparian areas with channel structures. However, it is critical to begin the planning process with the establishment of riparian objectives prior to developing watershed rehabilitation and treatment strategies. Riparian objectives should also be quantifiable and allow the land manager to determine the success of a particular project. Objective statements, such as "reestablish a willow riparian community with density of 20 thickets per hectare within 5 years by reducing spring livestock utilization to 20% and constructing 3 rock check dams," are measurable and meaningful to the land manager. Objectives such as these allow the manager to determine the projects success, benefit:cost ratios, and needs for improved techniques or implementation methods. Riparian vegetation establishment appears to have occurred indirectly or by chance rather than by design at Alkali Creek, the Silver City watershed, and High Clark Draw.

Riparian objectives should address the potential for natural regeneration or determine if planting is needed. Natural regeneration may require longer time periods and thereby is dependent on a seed source and the right conditions to induce germination and establishment. Rapid and more reliable establishment of riparian species can be accomplished through plantings and cuttings. Riparian objectives should determine the need for planting and the problems associated with introduced species, if used. Introduced riparian species may be undesirable from a habitat standpoint, a plant diversity standpoint, or may not be capable of surviving under the climatic conditions found in the treatment area.

In addition to the above concerns, treatment objectives must consider maintenance needs along with the effect of both channel structures and riparian areas on channel dynamics. Long-term maintenance of riparian health may require provisions for future maintenance of structural improvements and the management of a delicate balance between vegetative use and nonuse.

Monitoring objectives are equally important and should be established in accordance with treatment objectives. Assurance of long-term structural stability and integrity will depend upon monitoring. Recent flooding, or encroachment of riparian vegetation on spillways, may require immediate repair or vegetative management to protect the structure. Design should include the cost of future maintenance and determine whether maintenance levels are acceptable, or if higher design standards are needed.

Long-term maintenance of riparian areas may also involve a balance between use and nonuse. Complete exclusion from grazing may not be a viable management alternative. Observations on the Silver City watershed indicated that willows excluded from grazing became decadent and lost vigor. A certain level of periodic pruning by livestock or beaver *Castor canadensis* may be necessary to maintain healthy, vigorous willow stands. Application of good range management principles is equally important to assure livestock stocking levels that will minimize damage to the watershed and more importantly protect new riparian areas.

Because riverine riparian ecosystems tend to be linear in form, they serve as corridors for transporting water and erodible material derived from the surrounding landscape (Brinson et al. 1981). Consequently, using channel treatments to enhance riparian vegetation has some risks, and prior to implementation, their limitations must be recognized (DeBano and Heede 1987; Schmidt 1987). Of particular concern is the effect of different treatments on stream and channel dynamics. Structures such as check dams or small earthen dams remove only a small portion of the sediment load passing through the drainage system. Larger structures (earthen dams with large storage capacities) can remove almost all of the sediment from flowing waters as storage occurs. In this case, "clean water" has a greater energy to erode downstream channels and banks and can result in damage to the structure and associated riparian vegetation. Structures such as these may require additional spillway or downstream protection.

Another important feature of check dams or gully plugs is that they can be designed at spacings which transform turbulent flow into smoother, slower flows. The combined result is a stable channel with a static or aggrading base level. This provides improved sites for growth of riparian vegetation both upstream and downstream. Yet, if riparian vegetation encroaches on structures and seriously diminishes the flow capacity of spillways, flows may damage the structure's integrity. Diverted spillway flows can erode channel banks, create new channel systems, and dewater alluvial areas which can destroy established riparian areas.

Summary

Channel structures, in conjunction with comprehensive watershed management, have proven effective in rehabilitating deteriorated riparian areas in the southwestern USA. Channel structures store sediments, aggrade and stabilize channels, raise water tables, and extend base flows or create perennial flows. Saturated flows enhance soil moisture and aid in the maintenance and establishment of riparian vegetation. Although rehabilitation treatments can enhance or establish riparian areas, success depends upon treatment intensity, climate, topography, and watershed size.

A systems approach should be used when planning watershed and riparian rehabilitation. This approach should consider cause and effect relationships, landscape and vegetation potentials, land use management, and future maintenance. Quantifiable objectives should be established that consider the need for riparian planting, structural design and maintenance, watershed management, and the effects of structural treatment on channel dynamics. Monitoring programs need to be developed to evaluate the success of the project and determine if treatment objectives are met.

In the final analysis, land use managers must consider riparian objectives when planning watershed treatments. When properly implemented, channel treatments can be used to reduce sediment and peak flows to downstream users, improve wildlife habitat, increase recreational opportunities, enhance aesthetics, and successfully rehabilitate or create new riparian areas.

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Response of Juvenile Steelhead to Instream Deflectors in a High Gradient Stream

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Abstract.—Stream channel characteristics and juvenile steelhead *Oncorhynchus mykiss* populations were estimated before and after placement of boulder/rock triangular wing deflectors in 10 sections of a northern California stream in an effort to improve rearing habitat. An equal number of control sections were monitored. Following winter flows in 1981-1982, 14% of the structures were functionally intact. Changes in fry and parr numbers, densities, biomass, and standing crops in treated sections were not significantly different from changes in control sections. Condition factor of parr in 1982 was significantly reduced in treated sections following winter flows. A significantly lower percentage of marked parr remained in treatment sections following alteration. A review of similar habitat improvement evaluations indicated projects that increase populations have usually been sited on lower gradient (mean=1.0%) stream reaches. Projects that did not demonstrate population increases were generally on higher gradient (mean=1.8%) stream reaches, and results, although valuable, are less frequently published.

The placement of instream structures for the purpose of improving salmonid habitat is a common management practice. Large organic debris or other roughness elements that contribute to instream fish habitat may be reduced or absent in riparian areas and the addition of instream structures provides these habitat components. Instream structures are sometimes proposed as compensatory mitigation for habitat loss (U. S. Department of Transportation 1979; Babcock 1982; U. S. Army Corps of Engineers 1987). Instream structures have been shown to increase resident salmonid numbers or harvest (Shetter et al. 1946; Boussu 1954; Saunders and Smith 1962; Jester and McKirdy 1966; Hale 1969; Hunt 1969, 1976; White 1975; Binns 1980; Burgess and Bider 1980; Lere 1982). Although there have been fewer reports of increased rearing populations due to instream structures from the west coast of North America (Ward and Slaney 1979,1981; Overton et al. 1981; Moreau 1984; West 1984, House and Boehne 1986), this technique has the potential to augment returns of anadromous salmonids to both commercial and recreational fisheries. While appealing to riparian managers because of this potential, few instream habitat manipulations in the Pacific Northwest have included evaluations of physical habitat change and associated salmonid population response (Reeves and Roelofs 1982).

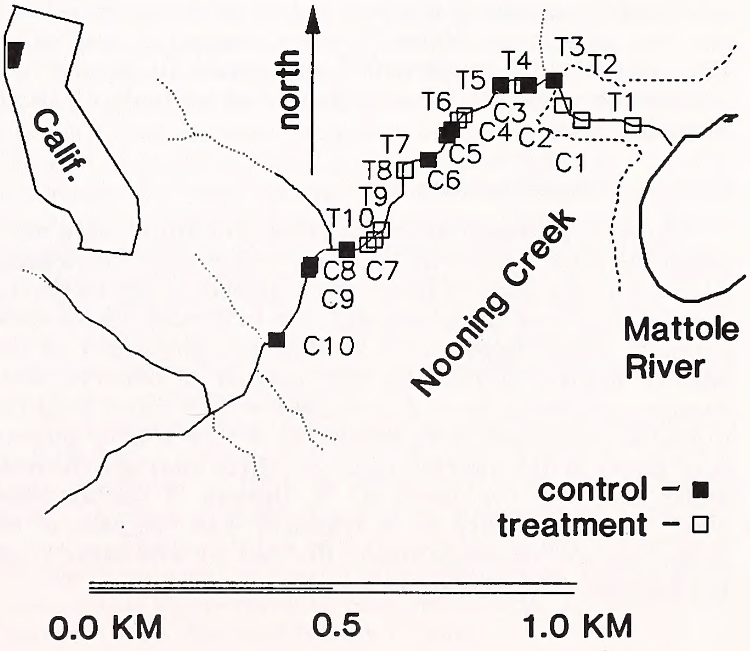
In 1981, an effort was made to place boulder/rock deflectors in a coastal stream in northern California. The purpose of this study was to quantify the change that resulted from the manipulation of juvenile steelhead (anadromous rainbow trout) *Oncorhynchus mykiss* habitat through the installation of inexpensive boulder/rock current deflectors. This evaluation included before and after measurement of physical habitat and fish populations, parr condition, and parr movement following the placement of deflectors.

Study Area

Nooning Creek drains 375 hectares and is located approximately 80 km south of Eureka and 3 km east of Shelter Cove in Humboldt County, California. The stream is a tributary of the Mattole River and within the King Range National Conservation Area (Figure 1). Stream length is approximately 3 km. The overall slope of the watershed is 14%, and the stream gradient from the upper study section to the mouth is 3.8%. Most study sections were within a second order channel (Strahler 1957).

Almost the entire watershed of Nooning Creek was logged in the 1960s, severely burned in the fall of 1973, and salvage-logged in 1976 (U. S. Bureau of Land Management 1982). Tractor logging techniques apparently included the use of the streambed itself. Numerous roads and skid trails cover a large area of the watershed, and associated sedimentation may have contributed to a wide, shallow stream channel that contained minimal instream cover (U. S. Bureau of Land Management 1982). Hardwoods and shrubs (in particular, *Ceanothus* sp., *Lithocarpus densifloris*, *Alnus* sp., *Arbutus mensiesii*, *Umbellaria californica*, and *Equisetum* sp.) were the dominant vegetation in the watershed at the time of this study, with some second growth Douglas Fir *Pseudotsuga menziesii* and Redwood *Sequoia sempervirens*. With the exception of shrubs or an

Figure 1.—Location of Nooning Creek and study sections.



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occasional small tree, vegetative canopy was generally absent from the riparian zone.

Mean annual precipitation is between 130-180 cm, 90% of which falls from October through April (Elford and McDonough 1974). Most precipitation is rain, often associated with high intensity storms. A relatively stable base flow between 0.75 to 2.19 m^3/min was recorded during the study period from June through mid-September in 1981 and 1982.

Little, if any sport fishing takes place in Nooning Creek. Fry population and density estimates in the spring of 1981 showed that steelhead trout were the only species of fish present in Nooning Creek and that the stream was seeded at or near capacity (T.D. Roelofs and J.B. Hamilton, unpublished). Due to the wide, shallow nature of the channel, summer rearing habitat was believed to be the major limitation to the production of steelhead parr and smolts from Nooning Creek. Instream deflectors were intended to constrict the channel and create additional habitat by increasing depth and velocity as well as providing some instream cover (U. S. Bureau of Land Management 1982).

Methods

Nooning Creek was chosen for habitat manipulation because (1) the riparian and channel conditions had been degraded and it was believed habitat would be improved by enhancement efforts; (2) the size of the stream is conducive to electrofishing and, therefore, evaluation of habitat improvement efforts; (3) nearly the entire watershed is within the jurisdiction of the U. S. Bureau of Land Management.

The stream was delineated into 30.5-m sections (straight midline length). Similar gradients, substrate composition, and riparian conditions were identified for 43 adjacent stream sections. Habitat condition for these sections was estimated as a percentage of optimum habitat (Duff and Cooper 1978). Of these, 20 sections with a low percentage of optimum habitat (30-64%) that were accessible to work crews were selected for the study. Of these, 10 control and 10 treatment sections (Figure 1) were selected randomly and permanently marked. The upstream 22.9-m of each section was designated for alteration and monitoring. A 7.6-m buffer section remained downstream between adjacent control or treatment sections. The buffer was intended to minimize the interaction of fish populations between adjacent sections. From 26 August to 2 September 1981 and 16 to 26 August 1982, physical habitat and fish population variables were estimated in control and treatment sections.

Physical Characteristics

Physical dimensions of the stream channel were measured the flow. Wetted widths were recorded to the nearest 3.0 y 2.3 m at transects perpendicular to cm. Depths (to the nearest cm) were measured at 0.3-m intervals across each transect. Mean depth for a section was computed as the sum of depths divided by the number of observations. Stream gradients were determined with a hand held clinometer. Velocities were measured with a Gurley pygmy flow meter at one quarter, mid, and three quarters channel width at 0.6 of the depth (U. S. Bureau of Reclamation 1967). Mean velocity for a transect was the sum of all cross-channel determinations divided by one more than the number of velocities measured.

Population Estimates and Marking of Parr

Electrofishing was done in late August and early September 1981, June 1982, and late August 1982. Block nets were first placed across the downstream boundary of each 22.9-m section to avoid disturbing fish upstream. Each section was electrofished at least twice and as many as five times; each pass was timed to insure equal effort. Fish from each pass were isolated in live boxes or buckets until electrofishing was completed, then anesthetized, measured, weighed, allowed to recover, and (after all passes were completed) returned to the section. In areas where fish could stray into a nearby unfished section after release, block nets were set up prior to release to prevent movement between sections.

Population estimates were calculated for fry and parr by the Moran-Zippen removal method (Everhart et al. 1975). Probability of capture estimates and standard errors were calculated according to Everhart et al. (1975). Variance computations were equivalent to those of Zippen (1956,1958); for populations less than 200, the method provides 90% rather than 95% confidence limits. Population estimates were not calculated for June 1982.

Individual parr weights were recorded to the nearest 0.1 g on a triple beam balance. Condition factor (K) was calculated from the following equation:

$$K = \frac{W \times 10^5}{L^3}$$

where W = weight in grams and L = fork length in millimeters (Everhart et al. 1975). Condition factors were not computed for fry.

Biomass estimates of fry and parr within sampled sections were calculated by multiplying the average fish weight and the estimated total number. When an estimated total number of parr was equal to the actual number sampled in a section, parr biomass was considered the sum of actual fish weights. During the study, 97% of the total parr estimated were measured and weighed individually.

Standing crop (biomass/m^2) was computed as the total biomass estimate divided by the area of the sample section. Variances and standard errors of estimates of biomass and standing crops were computed by the delta method of approximation in a propagation of error context (Seber 1973). Fry were weighed in batches of 10 fish. The equations for variance and standard error for fry biomass estimates are reported in Hamilton (1983). Because variance was not assigned to population estimates of parr, no confidence interval was assigned to parr biomass and standing crop estimates.

To test the null hypothesis that alteration did not affect summer residency (defined as the number of fish tagged in June 1982, which remained in August 1982), parr were marked with combinations of opercular marks and fin clips to identify the section of origin. To avoid more than two marks or clips per fish, each of the ten combinations was used in two sections. Sections with identical marks, however, were never closer than 0.5 stream kilometers. When recovered in August 1982, marked fish were assumed to have come from the closest section where that mark had been used.

Alteration of Habitat

Strict design criteria for deflectors were not developed. A maximum flow of 68 m^3/min was expected (U. S. Bureau of Land Management 1982). Angular boulders and cobble size rock were used to construct triangular wing deflectors. Boulders and rock were taken from the vicinity of the treatment sections. Methods recommended in stream improvement manuals (White and Brynildson 1967; British Columbia Ministry of Environment 1980) were generally followed. Deflectors were installed by enthusiastic but inexperienced workers.

The largest boulders were used on the upstream face of each deflector. This usually resulted in smaller boulders and cobble being used inside the triangular perimeter. Rock for construction was removed from the channel if its removal would deepen and narrow the channel. Larger boulders were removed manually with a pry bar or by using a grip hoist. Deflectors were alternated side to side every four to six low-flow channel widths and angled into the flow at 20° to 45° (angle of deflection). If the opposite bank downstream was not armored by bedrock or another deflector, this area was, in most cases, protected with rip-rap. Deflectors and revetment or rip-rap were arranged with the intent to use the hydraulic forces of the stream to narrow and deepen the channel. Deflectors were placed in treatment sections during October 1981.

Results

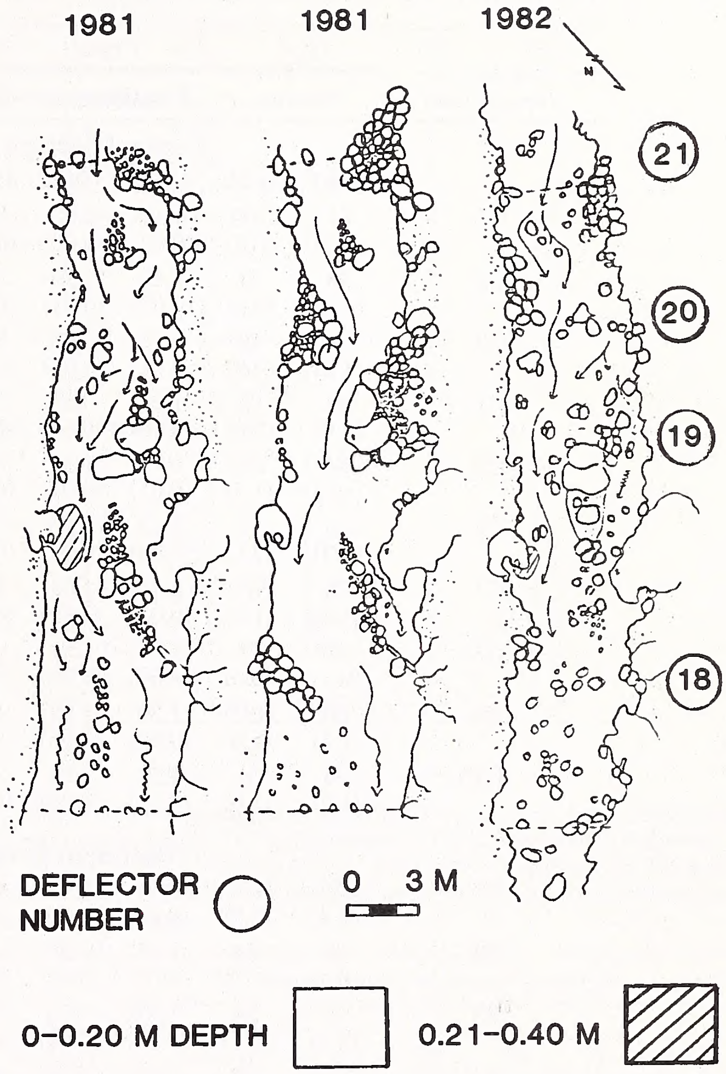
Deflectors were surveyed in May 1982. At this time, 5 of the 37 deflectors remained intact and were functional. Over 50% of the structures had collapsed and broken up (Table 1). The peak flow (estimated using Manning's equation) to which deflectors were subjected was 234 m^3/min. Although no long term discharge records were available for Nooning Creek, the peak flow for the Mattole River at Petrolia, California during this period was a relatively common storm event (5 to 7-year occurrence; M. Weston, USGS, personal communication). Deflectors generally broke up with all but the largest boulders displaced downstream (Figure 2).

Table 1.—Durability and function of 37 boulder and rock deflectors in treatment sections of Nooning Creek, California, following the winter of 1981-1982. Sections were evaluated in May 1982.

Section	Undamaged and functional	Partially damaged but functional	Present but nonfunctional	Lost
T1			1	3
T2		1		3
T3	1	2		
T4				6
T5		1		3
T6	1	1		2
T7	1			2
T8		1		2
T9			1	1
T10	2	1		1
Total	5	7	2	23

To a degree, depths in the treatment sections increased due to deflectors. The increase in number of observations in depth strata greater than 10 cm and within 0.3 m of bank was significantly greater ($P\leq0.025$; paired sample *t*-test) in treatment sections. No significant differences ($P>0.05$; two sample *t*-test) in change in mean width, mean velocity, or maximum depth of each section were observed between control and treatment sections (Table 3).

Figure 2.—Nooning Creek section T5 before and after alteration.



Fish captured during August and September sampling periods that were greater than or equal to 95 mm (fork length) were considered to be parr based upon length frequency histograms and examination of scales. In June 1982, fish greater than or equal to 75 mm were considered to be parr. Because fry populations in all sections were less than 200, 90% confidence limits were given to the estimates (Zippen 1956,1958). For populations less than 50, variance estimates are poor (Zippen 1956,1958). Because all parr populations were below this number, confidence limits were not assigned to parr population estimates (Table 2).

Steelhead population parameters were not affected by habitat alteration. Changes in numbers, densities, biomass, and standing crop for both parr and fry were not significant ($P>0.05$; two sample *t*-test) between control and treatment sections (Table 2).

Post treatment condition of parr in altered sections was significantly poorer ($P<0.001$; one way ANOVA; Table 4) than condition in 1981. In addition to a decline in condition, the summer residence of parr was reduced in treated sections. The percent of parr remaining in treated sections (Table 5) between June and late August was significantly lower than the percent of parr remaining in control sections ($P\leq0.05$; Mann-Whitney U-test).

Table 2.—Mean (SE) estimated juvenile steelhead populations, densities, and biomasses for control (C) and treatment (T) sections of Nooning Creek, 1981-1982.

Section or comparison	Fry						Parr					
	Number		Number/m^2		Biomass/m^2		Number		Number/m^2		Biomass/m^2	
	Control Section (no current deflectors)											
	1981	**1982**	**1981**	**1982**	**1981**	**1982**	**1981**	**1982**	**1981**	**1982**	**1981**	**1982**
C1	61 (1.7)	100 (2.8)	1.17 (0.03)	1.98 (0.06)	3.76 (0.20)	6.70 (0.99)	1	4	0.02	0.08	0.53	1.36
C2	88 (4.9)	71 (2.1)	1.19 (0.07)	1.29 (0.04)	2.67 (0.16)	4.41 (0.24)	2	7	0.03	0.13	0.70	3.73
C3	56 (1.2)	92 (2.9)	1.10 (0.02)	1.68 (0.05)	2.85 (0.10)	4.05 (0.28)	1	1	0.02	0.02	0.50	0.47
C4	92 (3.6)	62 (2.6)	1.27 (0.05)	0.88 (0.04)	3.07 (0.16)	2.82 (0.19)	0	2	0.00	0.03	0.00	0.54
C5	84 (0.6)	103 (1.2)	1.77 (0.01)	1.34 (0.02)	5.32 (0.22)	3.99 (0.12)	3	7	0.06	0.09	1.35	2.05
C6	56 (1.3)	70 (2.5)	1.12 (0.03)	1.45 (0.05)	3.51 (0.09)	4.51 (0.25)	6	7	0.12	0.14	3.75	3.17
C7	75 (1.6)	67 (1.5)	1.47 (0.03)	1.04 (0.02)	4.99 (0.17)	3.48 (0.26)	6	8	0.12	0.12	1.85	2.14
C8	83 (2.1)	73 (2.5)	1.32 (0.03)	1.51 (0.05)	4.07 (0.18)	4.46 (0.19)	1	6	0.02	0.12	0.22	2.29
C9	66 (1.7)	143 (4.0)	1.20 (0.03)	1.69 (0.05)	4.07 (0.25)	4.37 (0.47)	4	9	0.07	0.11	1.75	1.77
C10	65 (1.2)	51 (1.0)	1.59 (0.03)	0.94 (0.02)	4.66 (0.16)	3.02 (0.18)	2	8	0.05	0.15	0.63	2.61
	Treatment Section (deflectors added)											
T1	93 (0.4)	134 (5.3)	1.87 (0.01)	2.37 (0.10)	5.25 (0.28)	8.07 (0.43)	3	4	0.06	0.07	1.53	1.38
T2	68 (0.6)	66 (1.2)	1.41 (0.01)	1.25 (0.02)	4.70 (0.23)	4.11 (0.26)	2	5	0.04	0.09	1.24	2.37
T3	99 (2.4)	98 (2.1)	1.82 (0.04)	1.85 (0.04)	5.89 (0.23)	6.17 (0.37)	6	5	0.11	0.09	3.88	2.16
T4	114 (6.0)	87 (4.6)	1.96 (0.11)	1.22 (0.07)	4.97 (0.49)	2.65 (0.17)	0	0	0.00	0.00	0.00	0.00
T5	80 (5.6)	119 (3.2)	0.92 (0.07)	1.41 (0.04)	2.56 (0.19)	3.82 (0.23)	1	5	0.01	0.06	0.23	1.12
T6	96 (2.7)	73 (1.2)	1.83 (0.05)	1.49 (0.03)	4.89 (0.33)	3.75 (0.31)	0	4	0.00	0.08	0.00	1.30
T7	78 (1.7)	56 (1.6)	1.72 (0.04)	1.16 (0.03)	5.22 (0.30)	4.06 (0.29)	4	6	0.09	0.12	2.95	2.67
T8	116 (1.8)	103 (1.6)	1.71 (0.03)	2.56 (0.04)	5.52 (0.15)	8.10 (0.63)	2	6	0.03	0.15	0.48	3.46
T9	65 (6.6)	102 (2.4)	0.84 (0.09)	1.12 (0.03)	2.83 (0.30)	3.32 (0.11)	3	7	0.04	0.08	1.03	1.87
T10	88 (1.3)	77 (1.9)	1.58 (0.02)	1.65 (0.04)	5.80 (0.24)	5.38 (0.35)	2	6	0.04	0.13	1.29	2.71
	Mean Change, 1981-1982[a]											
Control	10.60		0.06		0.28		3.3*		0.05*		0.88*	
Treatment	1.80		0.04		0.18		2.5*		0.05*		0.64	

[a] Asterisks denote significant increase from 1981 to 1982 (paired sample t-tests; ($P \leq 0.05$)). None of the comparisons between mean treatment and control changes differed significantly (two- sample t-tests; $P > 0.05$)

Table 3.—Physical low flow channel characteristics of control (C) and treatment (T) sections of Nooning Creek, 1981 and 1982.

	Mean width (m)		Mean depth (cm)		Maximum depth (cm)		Mean velocity (m/sec)		Number channels		Gradient (%)
Section	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982	1982
Control section (no current deflectors)											
C1	2.21	2.13	9.3	13.5	26	39	0.16	0.09	1	1	3.5
C2	3.78	2.82	6.9	7.8	16	21	0.19	0.15	2	1	2.0
C3	2.31	2.48	7.2	7.3	14	18	0.15	0.13	1	1	1.0
C4	3.16	3.10	5.1	6.3	25	19	0.19	0.14	2	2	2.5
C5	2.08	3.35	8.6	8.2	31	35	0.14	0.13	1	1	2.5
C6	2.18	2.11	11.7	12.2	65	34	0.22	0.24	1	1	5.5
C7	2.23	2.83	8.7	9.4	37	86	0.21	0.17	1	1	3.5
C8	2.75	2.12	5.5	6.2	17	21	0.22	0.16	1	1	3.0
C9	2.31	3.57	8.2	10.0	23	45	0.18	0.07	1	2	2.5
C10	1.82	2.42	8.2	6.6	25	24	0.17	0.20	1	1	3.5
Treated section (deflectors added)											
T1	2.17	2.47	9.9	9.9	24	20	0.13	0.10	1	1	1.5
T2	2.11	2.32	11.5	9.8	35	42	0.12	0.13	1	2	2.0
T3	2.29	2.23	10.8	12.3	31	36	0.15	0.06	1	1	2.0
T4	2.59	3.19	8.7	8.2	18	34	0.16	0.09	1	1	1.0
T5	3.81	3.68	4.8	6.9	21	20	0.13	0.10	1	1	1.5
T6	2.39	2.22	6.1	8.1	19	24	0.17	0.20	1	1	2.0
T7	1.98	2.12	7.3	21.3	24	89	0.20	0.11	2	1	4.0
T8	3.47	2.06	6.5	11.1	34	45	0.20	0.14	1	1	2.5
T9	3.39	3.98	6.5	9.2	46	36	0.20	0.11	1	2	3.5
T10	2.29	1.98	8.8	9.9	26	33	0.19	0.12	1	1	3.0

Table 4.—Condition factor (K) treatment sections of Nooning Creek, August 1981 to August 1982.

Date	Control	Treatment
August, 1981	1.266 ± 0.052	1.202 ± 0.046
August, 1982	1.269 ± 0.038	1.157 ± 0.042[a]

[a] Significantly less ($P<0.001$) than 1981 and August 1982 control sections (one way ANOVA)

Parr numbers and densities (Table 2) were significantly greater within control sections and within treatment sections in 1982 ($P \leq 0.01$; paired sample *t*-test). Parr biomass and standing crop were significantly greater in 1982 ($P \leq 0.01$ and $P \leq 0.05$; paired sample *t*-test) within control sections.

Discussion

The placement of instream deflectors can result in poor durability and may adversely affect salmonid populations if sited incorrectly, as they were in this study. Even with an increase in depths in sections with deflectors, the desired result of an increase in parr populations were not realized, at least in the 1-year period of evaluation within the scope of this study.

I feel the conclusion that summer residency was reduced is a valid one. Although no pre-treatment data are available, treatment and control sections were randomly selected. A similar percentage of parr remaining in treatment and control sections would be expected; what was observed, however, was a difference that due to chance alone would occur less than 1 time in 20. Identical marks were used in more than one section; however, I feel the assumption that

Table 5.—Percentages of steelhead marked in June 1982 and remaining in control (C) and treatment (T) sections with deflectors in August 1982, Nooning Creek. Fish were identified by fin and operculum clip combinations that were repeated only in widely separated sections.

	Percentage by recovery section[b]					
Marking section[a]	Section where marked	C7	T4	T5	T6	T8
Control section (no current deflectors)						
C1	27					
C2	36					
C3	33			33	33	
C4	29			14		
C5	67					
C6	60					
C7	33					
C8	40					
C9	78					
C10	50					
Treatment section (deflectors added)						
T1	33					
T2	100					
T3	0					
T4	0				100	
T5	17					
T6	20					
T8	17					
T9	29	7				14
T10	42		10			

[a] no fish were marked in section T7

[b] sections from which no marked fish were recovered are not listed

fish came from the closest section with that mark is reasonable. Edmundson et al. (1968) concluded steelhead parr maintained permanent stations in the summer months; most fish were observed within 6 m and no fish were observed more than 9 m from these stations.

It is unclear why reduced condition factors and summer residency were observed in treated sections. Madsen (1938) reported summer densities of benthic invertebrates were lower in stream sections adjacent to instream structures than in undisturbed sections. A reduction in prey organisms in Nooning Creek could have occurred because of increased scouring and destabilization of substrate. If so, this change may have contributed to both reduced condition factors and residency.

Changes to habitat parameters that were unmeasured, such as instream cover, may also have contributed to these declines. Ward and Slaney (1979, 1981) found that deflectors alone resulted in little increase in populations of rearing steelhead and coho salmon but that deflectors with cover added showed a greater increase in numbers of juvenile salmonids.

Although further observations would have been necessary to identify the exact mechanisms responsible for reduced condition factors and summer residence of steelhead parr in treated sections of Nooning Creek, instream alteration can have adverse effects on salmonid populations or result in no increase in salmonid populations as in this study. Riparian managers need to know that successful habitat improvement cannot be assumed and that even in a badly degraded stream, such as Nooning Creek, increased salmonid populations may not result.

Published evaluations of stream improvement efforts have not promoted this awareness. Results such as those from this study are seldom reported in published literature, nor are they widely distributed. A review of available documentations of instream habitat manipulation projects that include estimates of salmonid population response (Table 6) supports the assertion of Reeves and Roelofs (1982) that project failures are often not reported or are less willingly discussed or exhibited than are successful projects. Conversely, most published accounts report an increase in the population of trout or salmon.

A second generality is that successful projects, with few exceptions, are on streams with a gradient of 2% or less. In the Nooning Creek evaluation, the fact that only 14% of the deflectors remained after one winter of relatively common storm events indicates such inexpensive structures were unsuitable when sited in a high gradient stream. Although a number of considerations in deflector installation and siting, including spacing, orientation into the current, construction techniques, and size of available material, affect their function and durability, stream gradient may be the most important hydrological consideration. For current deflectors, durability in western streams appears inversely related to the gradient in the stream reach where deflectors are sited (Table 7).

Some stream improvement manuals and review papers recognize the importance of gradient in siting durable instream structures but gradient is discussed in relative terms only, with the caution that "high" gradient streams be avoided or that structures be sited in stream reaches with "low to moderate gradient" (Madsen 1938; White and Brynildson 1967; Parkinson and Slaney 1975; Wydowski and Duff 1978; British Columbia Ministry of Environment 1980; Raleigh and Duff 1980; Miller and Tibbott 1980). Two manuals that are exceptions are the U. S. Forest Service Wildlife Improvement Handbook (U. S. Forest Service 1969) which specifically recommends against using instream devices where gradients exceed 3% and a handbook on relocation of streams (U. S. Department of Transportation 1979) that provides criteria for rock size in streams with gradient greater than 3%. In coastal Oregon streams, Anderson et al. (1984) recommended reaches with gradients less than 2.5% and preferably less than 1.5% as site selection criteria for instream structures. Unfortunately, the importance of gradient continues to be unrecognized by many managers. At least one recent reference describing the use of deflectors to benefit habitat makes no mention of stream gradient in relation to siting criteria (U. S. Army Corps of Engineers 1987).

Although knowledge of unsuccessful projects, and therefore the consequences of siting instream structures in high gradient reaches, may be common knowledge among experienced managers, this information should be readily available to inexperienced managers.

Much remains to be learned about the effectiveness of instream structures on west coast streams. Knowledge is gained from evaluations (Ward and Slaney 1979, 1981; Overton et al. 1981; Moreau 1984; West 1984; House and Boehne 1986) that have shown an increase in rearing populations of anadromous salmonids and accurate reporting of other results (Barnhart et al. 1983; Everest et al. 1984; Petrosky and Holubetz 1985; Fontaine 1987). The latter provide valuable information on what has been attempted and insight into how structures and evaluation can be improved in the future. Documentation in Barnhart et al. 1983, for example, showed that, despite construction of instream structures to rigorous design criteria, siting in a high gradient reach of stream did not result in a detectable increase in salmonid populations. Without similar evaluations, and the opportunity to learn from all past projects, regardless of the results, instream habitat manipulation as a riparian management ool will remain an art rather than a science.

Acknowledgements

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Table 6.—Evaluations of instream structures and response of resident or rearing salmonid populations

Population Response/Mean Gradient (SD)	Published[a]			Unpublished[b]		
	Study	Structure	Gradient[c]	Study	Structure	Gradient[c]
Decline or No Change 1.83 (1.10)	Maughan et. al. (1978)	dams/gabion deflectors	1.2	Wilkins (1960)	dams/deflectors	1.0
	Harshbarger (1980)	channel constrictors	d	Richard (1963)	dams	3.0
	Babcock (1982)	dams/deflectors	2.7	Lowry (1971)	deflectors/cover	0.4
	Hartzler (1983)	half-logs	0.7	Latta (1972)	deflectors/cover	d
				Lere (1982) (Sheep Creek)	dams	1.7
				Barnhart et. al. (1983)	deflectors/ boulders dams	3.2
				Hamilton (1983)	deflectors	3.8
				Everest et. al. (1984)	boulder berms	2.0
				Petrosky and Holubetz (1985)	dams/deflector logs	1.0
				Fontaine (1987)	boulders/angle logs	1.2
Increase 0.99[e] (0.84)	Shetter et. al. (1949)	deflectors	0.1	Frankenburger (1968)	deflectors/dams	d
	Boussu (1954)	cover	0.3	Lere (1982) (Prickley Pear Creek)	rock jetties	0.8
	Saunders and Smith (1962)	dams/deflectors	0.6	Lere (1982) (St. Regis River)	rock jetties	1.5
	Jester and McKirdy 1966)	trash catchers/ dams	d			
	Hale (1969)	deflectors/cover	1.2			
	Hunt (1969, 1976)	deflectors/cover	0.3			
	Bjornn (1971)	large rubble	d			
	Boreman (1974)	dams/bank cribs	d			
	White (1975)	deflectors/cover	0.1			
	Ward and Slaney (1979, 1981)	boulders/ deflectors	0.6			
	Binns (1980)	dams/Hewitt ramps	d			
	Burgess and Bider (1980)	dams	d			
	Overton et. al. (1981)	boulders	0.9			
	Anderson et. al. (1984)	gabion	d			
	Moreau (1984)	boulders	1.9			
	West (1984)	boulders	1.6			
	House and Boehne (1986)	gabion v's	3.0			

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[a] published in peer review journals or symposium proceedings; MS theses not included

[b] includes MS theses

[c] gradient from documentation or determined from USGS maps and opisthometer; change in elevation based on nearest contour lines

[d] gradient not obtained

[e] gradients for projects which showed an increase in salmonid popula6ions were significantly less ($P<0.05$; Mann-Whitney U-test)

Table 7.—Durability of boulder and rock deflectors used to improve salmonid habitat on western streams and stream section gradient.

Stream and location	Reference	Type of deflector	Gradient (section)	Durability of structures	Period of evaluation (years)	Durability index[a]
Kaweah River (California)	Ehlers (1956)	Rock	3.3	0% (0/1)	18	0.0
Nooning Creek (California)	This Study	Boulder/ Rock	3.8	14% (5/37)	1	0.1
Ten Mile Creek (Colorado)	Babcock (1982)	Rock deflectors	2.6	50%	2	1.0
St. Regis River (Montana)	Lere (1982)	Boulder jetties	1.5	67% (12/18)	7	3.7
Keogh River (British Columbia)	Ward and Slaney (1979, 1981)	Boulder deflectors	0.6	Near 100%	5	5.0
Little Prickley Pear Creek (Montana)	Lere (1982)	Boulder jetties	0.8	87% (14/16)	16	13.9

[a] Number of years of evaluation × fraction of deflectors remaining

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EXTENDED ABSTRACTS

The following abstracts are provided as an informational service. These abstracts have not been peer reviewed and should not be cited in future publications or unpublished works.

The Development of Riparian Habitat Management on the Red Rock Lakes National Wildlife Refuge, Montana

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Abstract.—The Red Rock Lakes Refuge, located in the Centennial Mountains, Montana, is managed under a dominant-use doctrine with fish and wildlife values having high priority. The primary purpose of the Refuge is to provide habitat for trumpeter swans *Cygnus buccinator*, although considerable emphasis is devoted to providing and maintaining important habitat for more than 300 species of fish and wildlife.

Riparian habitats are critically important for the majority of these species. The continued presence of Arctic grayling *Thymallus arcticus*, which is listed as a Species of Special Concern by the Montana Department of Fish, Wildlife and Parks, is a management priority on the Refuge. Other fishes, such as cutthroat trout *Oncorhynchus clarki* and brook trout *Salvelinus fontinalis* are important species that serve as prey for mammalian and avian predators and as a recreational resource. Unpublished data collected from different habitat types of the Refuge revealed some of the highest species diversities and numbers of passerine birds found in riparian areas.

Livestock grazing, which began in the area in 1876, is believed to have had a significant negative impact on Refuge riparian habitats. Large numbers of livestock were grazed on what is now the Refuge from early settlement times until its establishment in 1935. Following establishment of the Refuge, intensive, season-long grazing continued on all riparian areas until the early 1980s when significant changes were made in grazing patterns. Electrofishing surveys, conducted in August, 1988, found low fish densities on Refuge streams. Estimates on Red Rock Creek showed only 4.2 Arctic grayling, 29.8 brook trout, 4.2 cutthroat trout, and 8.5 mountain whitefish *Prosopium williamsoni*/km. Estimates on Odell Creek indicated that 21.3 Arctic grayling, 104 brook trout, 102 cutthroat trout, and no mountain whitefish/km were present. Habitat surveys were conducted in 1988 on both Red Rock and Odell creeks using a combination of two Forest Service habitat indices: Stream Reach Inventory/Channel Stability Evaluation and Habitat Capability Model (COWFISH) (Table 1).

Table 1.—Mean (SD) and range of width, depth, and aquatic habitat and stream bank stability indices for Red Rock and Odell Creeks. Eight 30-m sections per stream were sampled in August, 1988. Reach scores are interpreted as: ≤38 = excellent; 39-76 = good; 77-114 = fair; ≥115 = poor.

Stream feature	Mean (SD)	Range
Red Rock Creek		
Width (m)	66 (1.9)	4.7 — 10.0
Depth (cm)	36.6 (22.9)	14.7 — 82.0
Total reach score	84.6 (19.3)	62 — 123
% undercut banks	23.1 (23.1)	0 — 70
% vegetation overhang	23.1 (23.6)	0 — 70
% bank erosion	25.0 (22.0)	0 — 50
% bottom covered with fines	43.8 (37.5)	10 — 100
Odell Creek		
Width (m)	5.5 (1.6)	3.6 — 8.30
Depth (cm)	24.6 (9.4)	15.2 — 42.7
Total reach score	94.9 (16.2)	75 — 116
% undercut banks	1.8 (3.5)	0 — 7
% vegetation overhang	9.0 (7.0)	0 — 15
% bank erosion	64.0 (23.9)	45 — 95
% bottom covered with fines	43.8 (37.5)	10 — 100

Because of the importance of riparian habitats to fish and wildlife species present, management actions have been initiated on and adjacent to the Refuge in recent years. The most important action has been a change in the grazing program. During the 30-year period from 1943-1973, an average of about 14,800 animal-unit months (AUM) were removed from the Refuge with annual, season-long grazing on all units. About 450-900 tonnes of hay were harvested from the Refuge during this period. Beginning in 1975, grazing was reduced on the Refuge by 50% over a 5-year period. In addition, when permittee ranches changed ownership, grazing permits were not renewed. Grazing pressure on the Refuge has been reduced to a level of 5000-7000 AUM at the present time.

The pattern of grazing was changed significantly after the stocking reduction. In 1980, about 23%, or 2,419 of the 10,408 hectares in the grassland management program were indefinitely deferred. Much of this land is significant riparian or willow *Salix* spp.-bog habitat. The remaining grasslands were placed in a rest-rotation grazing system where units are given complete rest for two seasons, and grazing is conducted from July to October in every third year only. Many units have been cross fenced into two sub-units, and each of these is grazed for half the normal season. This double rest-rotation system (Platts 1989) has reduced grazing pressure on riparian areas to 7 weeks every 6 years.

The use of one-wire electric fencing has been employed in recent years to completely exclude livestock grazing from significant riparian areas. A total of 2.3 straight-line km (6.9 river km) of Odell Creek was fenced on both sides. The cost of the project was $1,136/km of fence. Fencing has been successful in excluding livestock from other riparian areas on the Refuge as well.

The use of prescribed fire in late April-early May has been applied on Red Rock Creek, Tom Creek, and the Idlewild area from 1984 to 1987 to rehabilitate decadent willow stands and increase the number of live willow stems/unit area. Substantial rerooting and an increase in the number of stems were noted after each of the fires, especially in the Idlewild area, which was treated twice in 3 years.

The acquisition of land and associated water rights has been used recently to protect riparian areas and water flows through the Refuge. In 1986, the 706-hectare tract of the Companeros Cattle Company, which contains more than 4.5 km of Odell Creek and includes senior water rights on the creek, was acquired. Irrigation diversions from the creek had negatively affected the fishery of the stream, including damage to spawning beds used by Arctic grayling. Sediment from the sloughing creek banks was identified as a major source of sediment in Lower Red Rock Lake (Montagne 1987). In 1987, the Refuge also acquired a 1.9-km segment of Battle Creek, a small spring-fed creek that flows into Upper Red Rock Lake.

Since the quality of riparian habitats is heavily dependent on the condition of upstream watersheds, Refuge land managers and consultants are working with the U. S Bureau of Land Management (BLM) on the restoration of phosphate mining sites in the Odell Creek watershed and are providing information to BLM planners and managers concerning the proposed Centennial Mountains Wilderness that will encompass much of the Refuge watershed. The Refuge is also working with the U. S. Sheep Experiment Station to alleviate a sedimentation problem in the Tom Creek drainage. Exclosures have been installed to determine if sheep grazing is exacerbating already significant amounts of natural siltation from the drainage. The Refuge is monitoring sediment loads on Tom Creek in cooperation with the U. S. Geological Survey.

Working with a "challenge grant" from the U. S. Fish and Wildlife Service, the Refuge is cooperating with Trout Unlimited in a restoration effort on a recently acquired portion of Odell Creek. The Refuge, with technical assistance from other agencies, is currently developing a plan to allow for the most rapid recovery of this important riparian area. Structural changes, such as the replacement of culverts on the South Centennial Road, vegetative plantings of willows, and detailed water management guidelines will be integrated into the restoration of this portion of Odell Creek.

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Streambank Rehabilitation in Western Oregon and Washington Using Willow Species, Douglas Spirea, and Redosier Dogwood

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Abstract.—The Soil Conservation Service Plant Materials Center (PMC) in Corvallis, Oregon, introduced shrubs and trees in 1978 for the propose of stabilizing low-velocity, meandering streams, restoring riparian areas, and enhancing fish and wildlife habitat in the Pacific Northwest. Some of the same species also have potential for use as hedges, screens, windbreaks, and natural area landscaping. The initial evaluation plantings at the PMC included 150 vegetative collections of shrub and tree ecotypes. The eight most promising clones of willows *Salix* spp., redosier dogwood *Cornus stolonifera*, and Douglas spirea *Spirea douglasii* were selected for advanced testing in field plantings in riparian areas. Selection was based on growth rate, survival, basal stem density, form, and apparent freedom from serious disease pests. Standards of comparison included 'Bankers' dwarf willow *Salix cotteti* and 'Streamco' purpleosier willow *Salix purpurea*.

Since 1982, tens of thousands of rooted and unrooted cuttings have been distributed for field plantings in Oregon, Washington, and adjacent states. Data from these trials were used to support the public release of five new willow cultivars in 1988. 'Bashaw' Douglas spirea and 'Mason' redosier dogwood should be released in 1990. The releases will be made by the Soil Conservation Service in cooperation with the Oregon State Agricultural Experiment Station and the Washington State Agricultural Research Center.

The new willow cultivars are: 'Multnomah' (PI508553) Columbia River willow *Salix fluviatilis* at maturity is 2 to 6.5 m in height with slender upright branching, a narrow, compact form, a suckering habit, and narrow lance-shaped leaves. This is a threatened species, limited in its natural range to sandbars and banks along the lower Columbia River and tributaries. This cultivar was collected on the east bank of the Sandy River in Multnomah County, Oregon. This selection can form thickets and, thus, make it a valuable erosion control plant not only for riparian zones but for costal dredge spoils and moist, sandy, or gravelly sites. Columbia River willow is a colonizing pioneer plant and as such cannot tolerate shade. Potential area of adaptation includes western Oregon and Washington.

'Clatsop' (PI508554) hooker willow *Salix hookeriana* is a large multistemmed shrub, 2 to 6.5 m tall with stout branching and a dense, upright to spreading form. Hooker willow is native to the Pacific Northwest coast from California to British Columbia. Rapid initial growth rates and good survival have been obtained from this selection when tested on moist inland sites in western Oregon and Washington. The 'Clatsop' cultivar originally was collected from the Clatsop Dunes in Clatsop County, Oregon. It has potential for streambank stabilization and landscaping, vegetating costal deflation plains, banks of coastal marshes, and other moist, sandy areas along the coast.

'Nehalem' (PI508555) Pacific willow *Salix lasiandra* at maturity is 2 to 10 m tall with finely spreading branches, an upright to rounded form; leaves resemble peach leaves, and young twigs are bright yellow in winter. It was originally collected near the Nehalem River in northwestern Oregon. This cultivar is adapted to western Oregon and Washington and probably moist riparian sites in northern California where precipitation exceeds 76 cm/year. Pacific willow is noted for its tolerance to long-term flooding, indicating that 'Nehalem' may be valuable not only for streambank stabilization but also for vegetating the shorelines of reservoir drawdown zones.

'Placer' (PI508556) erect willow *Salix ligulifolia* is a multi-stemmed shrub, 1 to 5 m tall with relatively narrow leaves and an upright to rounded form, somewhat open at the base. In low-maintenance plantings, 'Placer' has established and survived more readily than other willows tested. The origin of this cultivar is Placer County, California. It is recommended for use in streambank stabilization and the restoration of riparian areas. 'Placer' also has potential for use a native hedges or screens, wildlife habitat, natural area landscaping, and windbreaks. Area of adaptation includes western Oregon and Washington and probably much of California where precipitation exceeds 12 cm per year. It grows on a wide variety of sites, from moist, well drained sands to poorly drained silt loams and clays.

'Plumas' (PI508558) sitka willow *Salix sitchensis* is a large, arborescent shrub, 2 to 7.5 m tall with an open, erect form. Leaves are dull green above and covered with dense, silvery hairs beneath. 'Plumas' exhibits a rapid early growth rate and upright habit and competes well with grasses and other vegetation under low-maintenance conditions. It had higher stem density compared to 22 other sitka willow ecotypes (accessions) tested. Collected in the Plumas National Forest, California, its recommended uses, site preference, and area of adaptation are similar to 'Placer' erect willow.

Restoration of Severely Eroded Streambanks Using Tree Revetments and Willow Revegetation on Diamond Creek, Caribou County, Idaho

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Abstract.—For most Intermountain Region streams, the loss of stable riparian vegetation community types initiates a sequence of stream erosion resulting in development of steep, unstable cutbanks. As stable willow *Salix* spp. and sedge *Carex* spp. communities are altered to less stable vegetation types, the natural resistance to bank erosion is reduced. Resultant stream instability contributes to sedimentation and a shallower and wider water column. These factors often represent significant salmonid habitat quality reductions.

Restoring natural channel stability and stable riparian vegetation can be a formidable task on these highly unstable, often vertical, bare streambanks located in high energy positions along the outcurves of the stream. Yet rehabilitating such sites is key to reversing aggradational trends resulting from artificial disturbances with stream riparian areas and to re-establishing associated high quality aquatic habitats.

Success with cutbank rehabilitation has been demonstrated on the Caribou National Forest near Soda Springs, Idaho. A reasonably inexpensive but effective method has been applied on Diamond Creek in the Upper Blackfoot River drainage since the fall of 1984. Severe cutbanks along a 10-km reach of the stream were treated in five separate phases (annually). The approach combined tree placements and willow plantings to rehabilitate eroded banks.

The lengths and heights of all cutbanks were measured to determine the number and size of trees to install at each site. Approximately 5- to 10-m high, densely branched subalpine fir *Abies lasiocarpa* trees were harvested and placed horizontally on the face of previously designated bare streambanks. Trees were oriented lengthwise parallel to the banks with tips pointing downstream. At each site, the first tree was located along the bank at the point furthest upstream, with the tree butt overlapping stable bank for a distance of at least 3 m. Each successive tree was placed on bare bank with at least 20% of its length overlapping the adjacent trees. A backhoe was used to transport and place individual trees into the channel. Each tree was secured to the bank by cabling to a deadman driven 0.6 m into the ground. Construction occurred during low streamflow periods in late summer and fall.

During the first year following tree revetment construction, frost action on the cutbank caused blocks of soil to break off and fall into the placed trees. During high runoff periods, these blocks would normally be washed away and deposited in-stream. With trees in place, the sediments remained on site, filling interspaces between branches in the lowest portion of the channel (below the trunk line). Such sites make excellent soilbeds for willow re-vegetation.

In the fall of the year following tree placement and after willow vegetation had entered dormancy, willow cuttings were obtained from individual plants growing on the streambanks adjacent to the treated sites. A 6-mm diameter steel rod with handle was used to bore holes in the sediments accumulated within branches of the year-old tree revetments. Willow cuttings were placed in these holes and extended approximately 0.6 m vertically (well below the local ground water table) into the sediments. Most of the length of the willow cutting was extended below the ground surface and at least half extended below the zone of saturation, or water level of the stream. Placement of willow cuttings within the protective branches of fir revetments allows them to develop in a very productive site, undisturbed by the erosive effects of the stream and free from competition with other less-stabilizing vegetation types.

The placement of trees along previously bare streambanks improves local stream hydraulics. Because bed roughness is increased, erosive energies are reduced in the vicinity of the revetment (and extended somewhat downstream). Total water width is reduced slightly, and water depths increased. Sediments previously aggraded in the channel are now flushed, leaving clean substrates. These conditions combine to provide overall improved aquatic habitat.

After more than 4 years, the revetment projects have proven effective in restoring stability and vegetation to the eroded cutbanks. Approximately 80% of the willows planted in 1985 have survived even after being subjected to a major flood and two consecutive years of severe drought.

Aquatic habitat and electroshocking surveys in Diamond Creek demonstrate the positive effects of local fisheries. Habitat quality in the 1984 project site has steadily improved, with a 70% improvement over pre-project conditions. Trout populations have increased in the treated segments to 200% of pre-project numbers as compared with a slight population decline in the control (untreated) stream segment.

The long-term benefits of such rehabilitation are invaluable. It is impossible to calculate the economic benefits derived from increased riparian habitat, channel restabilization, improved water quality, improved aesthetics, and other associated values. Limited economic analyses placed the value of these benefits at over $10,500/km. Cost of treatment was less than $1,900/km, which produces a benefit/cost ratio of about 5.5 or greater.

The Montana Rivers Study: Past, Present, and Future

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Abstract.—The Pacific Northwest Rivers Study was initiated in 1984 by a measure in the Northwest Power Planning Council's Fish and Wildlife Program. Funded by the Bonneville Power Administration, the study was designed to identify, assess, and rate the significance of river related natural resources values in Montana, Idaho, Washington, and Oregon and to produce a consistent and verifiable data base. The Montana Rivers Study (MRS), the Montana portion of the Pacific Northwest Rivers Study, included the assessment of resident fisheries, wildlife, recreational, natural, and cultural features along 4,000 reaches of Montana's rivers and streams. In addition to detailed descriptive and location information, each data base contains quantitative and qualitative data on key features of each resource area such as species abundance, fishing pressure, presence of species of special concern (fish and wildlife), boating suitability, scenic quality (recreation), scarcity, and scientific or educational use (natural/geologic features).

The data bases are managed in dBase III+ software; however, the programming can be compiled to run on any computer with MS/Dos operating system. Reports are available in hard copy, on 13.3 cm floppy disks, or through modems. The Natural Resources Information System (NRIS) in the Montana State Library is the data manager for the MRS. Direct all requests to NRIS: (406) 445-5356 (address listed above). In addition to data reports, NRIS can also provide criteria and other documents produced for MRS.

The MRS is an ongoing federal and state interagency project. During this year (1989) the rivers system will be converted from the state's water code system to the Environmental Protection Agency (EPA) River Reach Number System. The EPA reach system, a geographically continuous system with reaches linked to one another, will be available in a Geographic Information System by 1991 with coverages compiled at the 1:100,000 map scale. Other planned updates will include connecting the system to other agency data bases such as those of Heritage program, Montana Riparian Association, and federal land management agencies and adding new data for land ownership, special management areas, consumptive and nonconsumptive wildlife recreation, and river recreation to name a few.

Monitoring Techniques and Management Practices Applied to Two Riparian Areas in Central Wyoming

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Abstract. Preliminary data are provided on hydrological monitoring efforts, surface water level changes, and sediment deposits in response to check dams. A brief evaluation of check dam effectiveness is provided to aid similar ongoing efforts. Two riparian systems in central Wyoming were chosen based on the potential of the floodplain vegetation to respond to grazing strategies, the potential of retaining sediment loads to elevate and maintain water table elevations, and the availability of contiguous U. S. Bureau of Land Management (BLM)-administered public land. The two streams described are Bolten Creek and Murphy Creek.

A stilling well stream gauge and a suspended sediment sampler have been recording data on Bolten Creek since 28 March 1984. Twenty-six hydrographs have been recorded with peaks greater than 15 cm, and two of the hydrographs have peaks greater than 1.52 m. A rainstorm event from 30 July 1985 to 31 July 1985 was sampled, and eight total suspended sediment samples on hourly intervals were obtained. The suspended sediment concentrations ranged from 37,672 mg/L to 77,664 mg/L. We analyzed the data to produce a range of instantaneous suspended sediment yields from 14.25 kg/s to 168.37 kg/s. Since hourly samples were collected, the entire storm was integrated to produce a total suspended sediment load of 1,753.01 tonnes for this 7.03-h hydrograph.

Four check dams were installed on Bolten Creek during 1986. The check dams were constructed with steel fence posts, and erosion fabric was used only for an upstream apron. The erosion fabric was wired to fence posts and anchored with rock. Woven wire was attached to the fence posts and stood 33 cm above the bed and the banks. Live willow *Salix* spp. stems and sagebrush *Artemisia* spp. were used to weave an organic mat through the woven wire fence. The check dams were adequately keyed in to the bed and banks.

In June 1988, two check dams on Bolten Creek were surveyed to measure water elevation changes immediately upstream and immediately downstream of each check dam. The differences in water surface elevations were 17.1 cm and 12.5 cm. The elevated water table was seen to extend 20 m upstream, based on stream gradient and visual evidence of sediment deposition.

Next, sediment volumes were estimated upstream of three check dams by surveying a representative cross section downstream of the check dam that was unaffected by scour and comparing it to two or three cross sections above the check dam. The check dam locations were in straight, stable stream reaches with similar cross-sectional appearances. It was assumed that the cross section downstream of the check dam was similar to the two or three pre-check dam cross sections upstream of the check dam. All the cross-sectional data were plotted and sediment elevations upstream were corrected for stream gradient. The three check dams have retained estimates of sediment volumes, from the farthest upstream check dam to the farthest downstream check dam: 4.45 m^3, 6.06 m^3, and 11.44 m^3, respectively. In all cases, areas of sediment deposition were greatest just upstream of the check dam.

Three of the four Bolten Creek check dams were inspected during June 1988, 2 years after installation. The combination of woven wire and woven organic debris performed effectively for Bolten Creek. The three check dams retained large amounts of sediment. Erosion fabric was used only upstream of the check dams; it was not incorporated into the vertical check dam wall. Therefore, the Bolten Creek check dams were porous enough to allow the passage of flood flow volumes, yet they decreased velocities enough to deposit large amounts of sediment. The check dam farthest downstream did show some evidence of piping within the sediment deposit, and reinforcement of the check dam was necessary.

A manometer stream gauge has been recording stage on Murphy Creek since 6 August 1987. Eight hydrographs have been recorded with peak stages greater than 15 cm. Eight 5.08-cm diameter alluvial groundwater wells with a recording clock and chart were installed during June and July 1987. These wells range in depth from 3 m to 6 m. Three of these well gauges are located across the same section as the stream gauge. Wells A, B, and C are located on the floodplain at distances of 5.8 m, 16 m, and 31.4 m, respectively, from the stream water level sensor. This configuration of gauges allows for accurate monitoring of surface water-groundwater interactions. Check dams are being installed in August 1988 just downstream of these well gauges.

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A snowmelt event from 10 March 1988 through 26 March 1988 was monitored by the stream gauge and all three well gauges. The stream was shown to be gaining flow from the alluvium during the snowmelt regime. Responses in Well A to the rising stream level occurred when the stream rose 7 cm above its base level. Responses in Well B occurred at 13 cm and in Well C at 15 cm. There was a sequential time lag in water table response due to streamflow. It was proportional to the distance from the stream. During the first event on 10 March 1988, Well A responded 5.5 h after the rising limb intersected Well A's elevation. Well B's time lag was 12 h, and Well C's time lag was 24 h. During the last series of hydrographs, prolonged wetting of the alluvium was experienced by this snowmelt event. Well B maintained an elevated water table for over 3 d after the stream level dropped below its elevation. Well C maintained an elevated water table for over 6 d. Well A closely matched the stream's falling limb. Future monitoring will enable us to detect any elevation changes in the water table due to check dams.

Eleven check dams were installed along the Murphy Creek drainage in 1987. Of the eleven check dams, nine check dams were constructed of steel fence posts, with erosion fabric folded over and attached to woven wire fence. The erosion fabric was a physical part of the dam face, and in addition it was spread out both upstream and downstream of the check dam and buried to provide an apron for the channel bed. Erosion fabric was used on the dam face to retain the fine-textured sediment. These dams were 41 cm high. Two dams 61 cm high were built with steel posts and either barbed or woven wire. Erosion fabric was used only as bed aprons on these two check dams. Check dams were located along relatively straight sections of the stream with gently sloping banks.

Only one of the eleven Murphy Creek check dams was surveyed in June 1988 to measure water elevation changes immediately upstream and immediately downstream of the check dam (the remaining ten check dams were dry). The difference in water surface elevations for the one check dam was 7.3 cm. An elevated water table was seen to extend 22 m upstream.

Sediment volumes were estimated upstream of three check dams. The three check dams were chosen on the basis of the similarity of stream reaches upstream and downstream of the check dams. The three check dams have retained these estimates of sediment volumes (upstream to downstream): 0.10 m^3, 14.39 m^3, and 5.34 m^3.

On Murphy Creek, check dams with erosion fabric incorporated into the dam wall caused bank erosion around the check dam ends during peak flows; dams constructed with uncovered woven or barbed wire allowed peak flows through with minimal bank erosion. The erosion fabric, although permeable, did not have enough porosity for short duration flood flows. Of the dams without erosion fabric, the barbed wire fence appeared to be more effective in catching debris than the woven wire fence.

Willows and Wildlife of the Northern Range, Yellowstone National Park

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Abstract.—Willow communities on the northern range of Yellowstone National Park are an important component of this 100,000 hectare ecosystem. Based on exclosure data and historic photographs of the area, willow communities have been dramatically reduced in both their extent and stature by large numbers of ungulates (Houston 1982). Adverse impacts may also be occurring to other species and resources on the northern range but to date they have received little attention. The purpose of this paper is to document some of these impacts and to indicate future research and management directions.

Following public pressure, the program of controlling elk numbers by trapping and shooting was discontinued in Yellowstone National Park in 1968. A reappraisal of the history of the northern elk herd followed, and the basic management assumptions under which the National Park Service had operated for nearly 40 years were subsequently changed(Houston 1974, 1982). From an active attempt to limit animal numbers, a policy of "natural regulation" was implemented, based largely on the research of Caughley (1970, 1976, 1979). The basic premise of this model is that populations of wintering elk will be maintained at relatively stable densities in equilibrium with their food resources without causing adverse changes in plant species composition and structure.

Whether or not the assumptions of this model are accurate has been the focus of much debate (Beetle 1974; Chase 1986; Despain et al. 1986; Kay 1987). For example, the 1988 elk census counted over 19,000 animals, a steady increase since 1968 when numbers were reduced to 3,172 elk (Houston 1982). The equilibrium between elk and vegetation predicted by the natural regulation model has apparently not yet occurred. Regardless of the validity of this model, willow communities on the northern range exist in a state quite different from that potentially possible.

In northern Yellowstone Park, willows are widely distributed and occur in a number of settings including streambanks, hillside seeps, and pond margins. In many willow communities, browsing by ungulates removes growth from the previous year and prevents tall-growing species such as *Salix geyeriana* and *Salix bebbiana* from growing above 1 m (Chadde and Kay 1988; Chadde et al. 1988). Although elk, because of their large numbers, are the major consumers of willow stems, moose and bison also affect these communities, either directly by browsing or indirectly by trampling. The result has been a conversion of many tall willow stands to communities dominated by short-statured willows or herbaceous species.

A further consequence of repeated browsing is the probable decline in the establishment of willow seedlings, as adult plants fail to produce flowers and seeds. Fruiting buds, if formed, are set in the fall of the year and are typically nipped-off during the winter or early spring by browsing animals. A decline in willow numbers is likely, as decadent plants die and are not replaced by young seedlings. Field observations along streams of the northern range suggest that successful willow seedling establishment is an infrequent occurrence, likely related to the scarcity of seeds and browsing rather then a lack of suitable sites. This may partially explain an estimated 50% decline in the extent of northern range willows and other woody riparian species since the inception of Yellowstone National Park in 1872 (Houston 1982).

The status of the beaver *Castor canadensis* on the northern range has been well documented (Warren 1926; Jonas 1955). This once common animal, although probably at an artificially high level in the 1920s because of successful predator control by the Park Service, had essentially disappeared by the 1950s. Interspecific competition between elk and beaver for willow and aspen sprouts may be largely responsible for their decline. Since then, significant populations of beaver have not returned to the northern range (Kay 1987). The loss of beaver, "a major shaper of riparian habitats" (Naiman et al. 1986), has probably resulted in a host of changes to the extent and structure of willow and other riparian communities.

The importance of security cover and the fruiting shrubs associated with tall willow communities to the grizzlies of Yellowstone Park has been confirmed by numerous studies (Mealy 1975; Graham 1978; National Park Service 1982). Fruiting shrubs such as chokecherry *Prunus virginiana* and serviceberry *Amelanchier alnifolia* were likely much more common on the northern range than at present. Early explorers of the region reported large quantities of chokecherries along streams (Haines 1965; Langford 1972). Ungulate grazing has apparently reduced the abundance of preferred herbaceous foods, notably cow parsnip *Heracleum lanatum*, found in the moist undergrowths of aspen and willow communities (Chadde et al. 1988; Kay personal communication, 1989).

In the northern Rockies, wetlands dominated by structurally and compositionally diverse tall-shrub vegetation typically support the greatest number of songbird species of any vegetation type (Balda 1975; Wright et al. 1983). On the northern range, various warblers Emberizidae, warbling vireos *Vireo gilvus*, house wrens *Troglodytes aedon*, Lincoln's sparrow *Melospiza lincolnii*, and song sparrows *Melospiza melodia* require riparian shrub thickets for nesting and feeding (McEneaney 1988). The high cover value associated with stands of tall willows is also critical for protection from predators and adverse weather. A reduction in the abundance of this type and an increase in herbaceous vegetation may lead to compositional shifts as steppe songbirds replace those requiring more diverse shrub-dominated habitats.

Changes in the morphology of willow-lined stream channels due to livestock-use are well documented (Kauffman and Krueger 1984). Similar changes can be expected under a regime of heavy elk use. In general, as willows decline and become shorter, their effectiveness for stabilizing streambanks decreases. Herbaceous vegetation is less effective in binding soil and cannot prevent bank undercutting or sloughing that leads to wider and shallower channels. The warmer temperatures and the absence of overhanging branches and woody debris recruitment (in the form of willow twigs and branches) results in poorer aquatic habitats and fewer fish.

Under current management policies and continued high ungulate populations, further declines in the abundance of woody riparian vegetation appear inevitable. This trend affects many other species and resources and illustrates the numerous interconnections among the components of the northern range ecosystem. An understanding of these relationships is critical when making management decisions if the objective of the Park Service, to maintain the Yellowstone ecosystem in a near-pristine state, is to be met (National Park Service 1975).

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Riparian Management for Upland Drainage in Eastern Montana

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Abstract.—Today, many upland drainages in eastern Montana have no woody vegetation. Other drainages have various communities ranging from a few remnant western snowberry *Symphoricarpus occidentalis* to closed canopy green ash *Fraxinus pennsylvanica*. Severson and Boldt (1977) summarized speculations on the impacts of fire, buffalo, and livestock on woody draw habitats and suggested that even on favorable sites on the prairies, woody plants survive under difficult conditions caused by extremes of temperature, wind, and precipitation. They also noted the value of those habitats to both livestock and wildlife. We are attempting to reestablish woody species in upland drainages through grazing management.

We selected U. S. Bureau of Land Management grazing allotments in Big Horn, Custer and Powder River counties of eastern Montana where we were working to develop grazing management plans. Where season-long use had been the previous practice, three to five pasture, double rest-rotation grazing systems were established. These allowed an average of 24 months of undisturbed rest, the essential part of which was two consecutive growing seasons of no livestock use. In some cases, we were able to gather data on allotments after 2 years of nonuse by livestock, although that was not planned in the grazing system.

After a grazing system had been established, bareroot seedlings and 2- or 3-year old trees and shrubs were transplanted during the first spring of each new rest cycle. Wetter, more protected sites in the drainages were selected for the plantings. Cut cottonwood poles were planted using ideas outlined by Davis (1982) and York (1985). Those plantings were in wet soils at developed springs inside exclosures. Monitoring during the first years of this project (and ongoing) has been with photo points.

In upland drainages, results from the grazing systems were visible after 1 year of rest. Species such as basin wildrye *Elymus cinereus* and slender wheatgrass *Agropyron trachycaulum*, which had been unnoticed in some drainages, now were prominent in monitoring photos. Wood's rose *Rosa woodsii* and snowberry appeared from nowhere after 1 year of rest in some drainages. Even after grazing in the third year of the cycle, during the drought of 1988, those shrubs are still part of the rejuvenated vegetative cover. Sprouts around mature box elder *Acer negundo* were woody enough after 2 years of growth to withstand livestock browsing without being killed as younger sprouts had been in the past. Old stands of wild plum *Prunus americana*, which had been severely hedged year after year, have had an opportunity to put on leader growth and new sprouts that have withstood livestock use in the third year.

Our bareroot plantings have resisted adversities such as being planted in too wet an area, being planted during a drought, and being eaten by deer *Odococileus* spp. Some of the survivors have now escaped use by livestock in the first year of grazing after the rest period.

In our first attempt with cottonwood poles, 24 of 25 poles leafed out in their first spring. By fall, 13 of those died. By digging up the dead ones and looking at the root growth, we determined that they had been planted where soil moisture was excessive. The remaining 11 poles leafed out again in their second spring. However, near double the normal rainfall in June and July of 1987 drowned all but three of the poles. Their roots had developed to about 0.5 m in length. The three survivors had grown as many as 20 branches, some up to 1 m long, when they went dormant in their second year. Unfortunately, having been provided excellent ground cover within the exclosure, the rodent population increased and girdled the survivors during the winter. On other sites, some poles have survived into their third year.

Although our findings are preliminary, we are encouraged by the results to date. There is no dispute today that properly managed rest-rotation grazing improves range condition, especially for grasses. Our system of double rest incorporates that improved range condition, which draws livestock away from browsing, with the idea that the more mature the growth on trees and shrubs, the more likely they are to survive when subject to livestock use.

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Effects of Plant Structure and Composition on Upland Hydrologic Cycles: Juniper Woodlands

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Abstract.—When evaluating changes in riparian zones, major changes in upland plant community composition from sagebrush *Artemisia* spp. — bunchgrass *Festuca* spp. to juniper *Juniperus* spp. woodlands cannot be ignored. Juniper and pinyon *Pinus* spp. — juniper woodlands occupy approximately 2.6 million hectares in the western USA. Western juniper *Juniperus occidentalis* alone occupies 0.7 to 1.9 million hectares. It has been estimated that juniper has more than doubled its distribution and density in the last 100 years. These woodlands occupy an important position in uplands between the desert floor and the pine forests. Upland water cycles change as a result of vegetation alteration from sagebrush-bunchgrass communities to juniper woodlands, especially precipitation interception and transpiration. Although we are aware that plant composition and ecological condition of upland vegetation influences riparian zones, it is difficult to quantify the effects.

As upland vegetation succeeds from sagebrush-bunchgrass communities to juniper woodlands, major changes occur both above and below ground that influence sedimentation, runoff, infiltration, precipitation interception, and water use on the site. Total aerial canopy cover may or may not decrease, but canopy distribution significantly changes. Structure of the aerial canopy cover is altered from being widely dispersed to one of large interspaces surrounding dense clumped canopies. This change also affects litter distribution on the site. The canopy structural change affects precipitation interception and transpiration. Changes below ground also occur with the decline in fibrous roots of herbaceous plants, which primarily occupy the upper 30 cm, replaced by deeper rooted woody plants.

Runoff has been consistently correlated with kind and amount of vegetation. Precipitation events ranging from 3.8 to 7.6 cm/h have recorded runoff to be 4 to 9 times higher respectively, on bare soil than soil containing plant cover. The effect of spatial distribution of cover has not been documented. Sedimentation rates in a juniper woodland, however, have been reported to be 3 and 3.6 times higher than in sagebrush-bunchgrass and grassland communities, respectively. Sedimentation on bare ground has been reported to be 20 times higher than on a natural sagebrush-bunchgrass community. Both soil organic matter and aboveground biomass have been noted to be important factors in controlling sediment production. Widely dispersed litter and plant cover in a sagebrush-bunchgrass community may act as a more effective sieve for capturing sediment and dissipating energy from runoff than would occur in the more clumped distribution of a woodland. Fibrous root systems have also been observed (however not documented) to be more effective soil binders than woody plant roots.

Infiltration rates play a major role in both runoff and sediment production. Infiltration rates are influenced by aggregate stability, organic matter, mulch, standing crop, bulk density, and ground cover. Again, spatial distribution of these components has not been evaluated. It has been reported that soils occupied by fibrous roots have higher infiltration rates than soils occupied by tap rooted plants. As juniper dominance increases on the site and understory vegetation declines, characteristics desirable for minimizing runoff and sedimentation and maximizing infiltration rates decline in the interspace. We feel that larger interspace areas found in a juniper woodland will result in an overall increase in runoff and sediment production, a decrease in infiltration rates, and an increase in evaporation.

Soil water extraction is also altered on the upland as it changes from a sagebrush-bunchgrass to a juniper woodland community. Due to the evergreen character of juniper, and the winter persistent leaves on sagebrush, soil moisture is extracted from the soil at a more rapid rate early in the growing season as compared to a grass dominated site. More important is the change in depth of soil moisture extraction from the soil profile. It has been well documented that grasses effectively utilize water in the upper portion of the soil profile; however, shrubs can use moisture effectively well below 60 cm. Sites dominated by herbaceous vegetation are significantly wetter below 1 m in the soil profile than sites occupied by woody vegetation.

Interception of precipitation by western juniper tree canopies represents a considerable loss of moisture. Interception over a 12-month period, ranged from 53 to 71% in trees ranging in size from 4 to 10.4 m in height, respectively. Throughfall was 45% in the smaller trees and 28% in the larger trees. Stemflow only accounted for 2.3 to 0.8% of the total precipitation. In a single rainstorm of 58.2 mm, which continued for a 2-day period, 63, 76, and 90% of the moisture was intercepted by small, medium, and large trees, respectively. Percentage of moisture intercepted by trees may not decrease as precipitation increases if that precipitation comes as snow. Interception will decline with wind. If a typical western juniper canopy cover of 20% is selected and the canopy is made up of large trees, then the loss of moisture to the soil system would be approximately 14%. In woodlands exceeding 30% canopy cover, moisture loss could exceed 20 % of the total annual precipitation.

Soil water transpired by a juniper woodland can be estimated by knowing the size of the transpiration surface (juniper leaf area) and the rate water is passing through the leaf into the atmosphere, which is a function of leaf conductance and vapor pressure deficit. Leaf area is predicted by measuring the average basal area or sapwood area of the woodland. Leaf conductance is controlled by air and soil temperature, vapor pressure deficit, soil water, and plant water status. A tree with a basal diameter of 30.5 cm would have a leaf area of 188 m^2. Estimated total water use by this tree would be 53 L/d on a mild spring day and 121 L/d on a hot summer day. As the juniper stand increases in size and

density, transpiration and interception by the juniper trees easily accounts for the largest percentage of water received by the site.

Although there is strong evidence that water cycles are significantly altered as uplands change from a sagebrush-bunchgrass to a juniper dominated community, the impact to riparian zones is very difficult to quantify. Changes, however, in sedimentation, infiltration, and runoff in juniper woodlands suggest potential decreases in water quality, increases in peak flow, decreases in annual flow, and decreases in total annual water yields.

The Use of Aerial Photography to Inventory and Monitor Riparian Areas

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Abstract.—There is an increasing level of interest in inventory and monitoring of critical stream-riparian environments. The majority of this nation's wildlife either depend on riparian areas or use them proportionately more than other habitat areas. The U. S. Bureau of Land Management (BLM) has been involved in refinement of techniques to improve the accuracy and efficiency of data collection and analysis. One of the procedures recently implemented by BLM is the use of low altitude, large scale aerial photography as a practical method for assessment of riparian communities. The combination of aerial photography and color infrared film are very valuable for vegetation analysis. In the arid areas of the western USA, riparian communities are easily delineated from photography by color tone, shape, and pattern. Within BLM, standard photointerpretation techniques are employed to extract the following information: vegetation type and subtype, width of riparian zone; percent ground cover of trees, shrubs, and herbaceous vegetation; percent bare soil, and density of large shrubs and trees. Stream characteristics such as width, channel stability, bank stability, floodplain width, and percent stream shading can also be determined or inferred via interpretation.

For most BLM applications, 23 cm × 23 cm format photography acquired via mapping cameras is preferred. This format is easier to handle, interpret, and use in both the office and field. Several seasons of experience have shown that photography scales of between 1:2,000 and 1:3,000 are preferred for a majority of the streams encountered on BLM administered lands. This scale allows for stereoscopic coverage of a smaller stream with a single flight line. Larger streams with wider riparian zones will require photography at somewhat smaller scales, often with parallel and overlapping flight lines to assure good coverage. All riparian photography acquired for BLM is currently procured through competitive contracting procedures from commercial sources.

During 1987 and 1988, the BLM acquired large scale aerial photography on approximately 1,000 km of key riparian areas in six western states.

The primary purpose for most of this initial photography is to clearly establish base-line conditions from which to monitor changes. In the hands of professional resource specialists, these tools will greatly assist in the analysis and management of these critical environments.

To assist persons wishing to use these techniques, BLM has prepared a Technical Reference (TR-1737-2) which is available through the Printed Materials Distribution Section (SC-658B) at the authors' address.

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Fifty Years of Riparian Recovery on the Malheur National Forest A Camera Point Record

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Abstract.—About 1939, a few camera points were installed on the Malheur National Forest to monitor the effects of changes in management. Additional camera points have been established since that time. For this presentation, a set of camera points were selected showing long-term and short-term changes, changes under management, and with partial and total ungulate exclusion. In our judgement, the photographs are reasonably representative of the Forest.

The Wickiup exclosure series demonstrates recovery where livestock have been excluded. In 1932, the site displayed severe damage, with bare soil, a gully system, and only root wad remnants of riparian shrubs. Later photos showed rapidly improving conditions. By 1980, the stream was in excellent condition, and the willow *Salix* spp. appear to be recovering but are heavily browsed by deer. By 1988, the willow had died back due to wildlife browsing impacts.

The Camp Creek exclosure was installed in 1977. This series shows steady recovery with total ungulate exclusion. The initial photo shows a few small riparian shrubs and a fair herbaceous cover. By 1988, the few shrubs outside of the exclosure were mature, and the meadow was well vegetated. Inside of the exclosure, shrub recovery in terms of density, height, and reproduction is dramatic. These photos infer an impact by big-game utilization on the rate of recovery of a riparian area.

The Wickiup Creek photo site, located adjacent to the Wickiup exclosure, illustrates recovery under controlled livestock management. In 1939, there was an abundance of bare soil, heavy sediment movement, and no shrubs. By 1980, the stream is significantly narrowed with sedges *Carex* spp./rushes *Juncus* spp. dominant on the floodplains. Improved grazing management consisting of moderate utilization levels and a grazing system designed around riparian needs has enhanced the recovery.

Two camera points are presented for the South Fork of Murderers Creek site. One set, established in 1939, shows severe damage with gullying and loss of vegetation. Recovery of the meadow by 1956 was dramatic, but the stream channel remained in poor condition. In the late 1960s a check dam was installed. By 1982, healthy meadows and a recovering streambank are shown. The large alder *Alnus* spp. have continued to decline. By 1988, young alder are present throughout the riparian area. This site portrays recovery with improved livestock management aided by structural practices.

The second camera point was established in 1982. Improvements in shrub density show how rapidly recovery can occur under favorable conditions and livestock management. The years between 1982 and 1985 were moister than average. This favored shrub growth and aided in improving distribution of ungulate use. The site also shows the value of the sediment trapping abilities of rushes and sedges. The stream shows significant narrowing and improved stability.

The Vincent Creek series illustrates recovery of a riparian area managed under a moderate standard for forage utilization and a rest/rotation grazing system over a 10-year period. Both the shrub and herbaceous component have improved dramatically. In 1977, the shrub component was virtually absent. Today, shrubs are well established and are increasing in size and density. This site demonstrates the potential for riparian recovery under good livestock management and natural conditions favorable for shrub growth.

In 1937, Coxie Meadows was a severely denuded meadow. In the 1960s, structural improvements and controlled livestock use facilitated a more rapid recovery. By 1980, a healthy meadow had been established under a rest/rotation management system. The improved condition continues through 1988. Management now provides for a moderate utilization level under a deferred rotation management system.

Riparian conditions have improved dramatically over the past 50 years on the Malheur National Forest. The degree of recovery and the speed with which recovery takes place are dependent upon management strategies and natural influences. The use of camera points to monitor changes in riparian trend and conditions is highly effective and of significant value in presenting the riparian story.

Monitoring Intergravel Dissolved Oxygen Concentration to Evaluate the Effects of Nonpoint Sources of Pollution on Salmonid Incubation

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Abstract.—The Clean Water Act, its amendments and programs constitute a national water quality policy for the USA. Goals of the Act include protection and restoration of water quality that will provide for propagation of fish. Water quality standards are a prominent feature of the Act, prescribing biological and chemical conditions that must be met to support intended uses of the Nation's waters. Those intended uses include spawning and embryonic development of salmonid fishes.

The Idaho water quality standards for nonpoint sources of pollution included provisions for evaluating the effects of best management practices on beneficial uses through comparison to in-stream criteria. The State Division of Environmental Quality is now working on criteria for salmonid spawning focused on factors that directly influence survival of embryos to emergence. The proposed criteria will not allow pollutants originating from nonpoint source activities to cause intergravel dissolved oxygen in spawning gravels to decline below 90% of saturation of a concentration of 6 mg/L.

Incubating eggs and alevins require a continual flow of water to supply dissolved oxygen for respiration and to carry away metabolic wastes. Fine sediment entering the interspaces in clean gravel effectively reduces permeability through the spawning redd, which in turn reduces the delivery of dissolved oxygen to incubating eggs. This has been shown to directly influence successful survival of salmonid embryos (Chapman and McLeod 1987).

Measurement of intergravel dissolved oxygen would ideally occur within the egg pocket of redds constructed by spawning female salmonids. Sampling directly within the redds, however, would disturb valuable habitat and hamper successful incubation as gravels directly overlying the eggs would have to be excavated. More appropriately, intergravel dissolved oxygen should be monitored by locating and constructing simulated redds based on habitat preferences and excavation techniques used by the species of interest, sampling devices are placed directly within simulated egg pockets.

An excellent approach follows the method first documented by Hoffman (1986) in which he buried an intergravel pipe horizontally within the egg pocket and pumped water from the pipe to a dissolved oxygen measuring probe. The intergravel pipe consists of one 30.5-cm section of 3.2 cm inside diameter, 0.0025 cm continuous slot PVC well screen pipe, an internal intake tube, PVC end caps, a length of plastic tubing, and appropriate pipe fittings. The apparatus is buried within the simulated redd during the spawning season, and sampling is conducted throughout the incubation period.

The simulated redd must be located to meet the spawning preference criteria for the target species. These include water depth, water velocity, substrate size, and streambed morphology. This information is available for salmonid species from habitat suitability models of the U. S. Fish and Wildlife Service Instreamflow Group. The redd is constructed in a manner to simulate the actions of a spawning fish. Gravels are excavated from the bottom and allowed to flow in the current. This forms a depression in the streambed located immediately upstream from a mound of clean gravel. In nature, the largest particles in the substrate cannot be lifted by the female spawning fish. Those particles form a clean pocket centrum into which the fish deposits the eggs. This centrum is also simulated in the artificial redd. Egg burial is accomplished by excavating gravels immediately upstream of the constructed depression, allowing stream currents to carry the finer materials downstream below the redd, and gravels to drop into the egg pocket covering the intergravel pipe.

Monitoring is facilitated by pumping samples from the intergravel pipe through a length of tubing extended from the buried pipe to the sampling location. Periodic measurements of dissolved oxygen concentration are made throughout the incubation period and conducted during the expected diurnal periods of oxygen depression. A portable peristaltic pump, powered by a battery-operated hand drill, is used to extract water from the buried pipe in a manner designed to avoid oxygenation.

The intergravel dissolved oxygen procedure has an advantage over other sediment monitoring methods in that it evaluates the environmental factor directly responsible for spawning success and is less expensive and labor intensive than other methods.

The Division of Environmental Quality is now applying and refining the intergravel dissolved oxygen monitoring technique. Success of salmonid egg incubation and survival as related to factors of sedimentation in artificially constructed redds is being tested by the Division.

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A Survey of Values Associated with Riparian Conditions of a Stream Tributary to the Green/Colorado River

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Abstract.—Sediment and salt are important but often ignored contributions to nonpoint pollution in the semiarid western USA. Accelerated erosion and sediment/salt in stream flow are often thought to be caused by livestock grazing on rangeland in less than excellent condition. Poor condition streams are often downcut and show active bank rilling, bank sloughing, and piping. Lateral movements of gullies away from downcut streams through upland ecosystems are, in addition, contributing sources for increased sediment/salt pollution. Equally important, when downcut streams occur, associated riparian vegetation is often reduced in areal distribution, disappears, or is replaced by pseudoriparian plant species. Loss of riparian vegetation and the hydrologic support of limited riparian ecosystems may further reduce stream channel stability and sediment/salt trapping efficiency of the stream. These nonpoint source pollutants are transported to the stream by overland flow and ground water. With the value of stream and riparian zone stability in mind, the University of Wyoming, U. S. Bureau of Land Management, ranchers, and state agencies initiated a study in the cold desert of south central Wyoming.

This study was located along Muddy Creek between Rawlins and Baggs, Wyoming and was designed to:

(1) Evaluate the use of wire faced dams to enhance the restoration of a degraded stream channel reach and thus the adjoining riparian zones.

(2) Evaluate the amount of sediment and salt stored by riparian zones along Muddy Creek.

(3) Evaluate the surface and ground water regimes associated with degraded, improving, and improved stream channel reaches along Muddy Creek.

(4) Evaluate vegetation response between a degraded and improving stream reach along Muddy Creek.

(5) Compare economic returns of riparian zones supported by different stream channel conditions to the cost of restoring them using sediment, salts, vegetation, and stored ground water.

Preliminary results show that riparian zones filter sediment from streamflow. Diversion and flood irrigation, flooding by beaver dams, and water spreading controlled by dikes have been successful in creating a surface aquifer/riparian zone in a desert ecosystem that is valuable for reducing nonpoint pollution and for prolonged storage of water during late summer months. Sediment can be trapped and vegetation production increased using wire faced dams in desert streams. Because of confining bed material under and along the existing channel, storage of water and creation of surfaced aquifer with dams was limited to the sediment storage capacity within the existing downcut stream channel. Both water diversion and damming of streamflow show improvement in riparian zone vegetation and control of nonpoint pollution when compared to a degraded stream reach.

Our study shows that stored sediment, trapped salts, increase in vegetation, and perhaps stored water in riparian zones, when using wire faced dams, will provide benefits sufficient to cover cost of construction and maintenance for federal and state agencies as well as municipalities but not the private producer. However, water diversion, water spreading, and creating a surface aquifer may increase riparian vegetation and store water sufficient to pay back the investment for these water development practices used in the past by private land owners.

Revegetation of Riparian Sites in Central New Mexico

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Abstract.—For purposes of restoring native habitat diversity; providing mitigation for construction, operation, and maintenance activities; effecting erosion control; and controlling saltcedar *Tamarix chinensis* by shading, the U. S. Bureau of Reclamation, with the assistance of the U. S. Soil Conservation Service, has planted native Rio Grande cottonwood *Populus fremontii* var. *wislizenii* and willow *Salix gooddingii* and *S. nigra* ecotypes, and six hybrid poplars *Populus* spp. through the use of unrooted, dormant, hardwood pole cuttings. Pole cuttings are the severed boles of saplings or, occasionally, the severed branches from young or mature trees. Between 1976 and 1987, nearly 4,650 pole cuttings of these species were planted at 13 environmentally varied sites along the Rio Grande River in central New Mexico. A number of the sites were, at the time of planting, on infrequently inundated flood plain areas of Caballo and Elephant Butte reservoirs. The unrooted poles, ranging in age from 1 to 4 years, were placed into holes that were augered to depths where the poles would be resting in ground water throughout the growing season. Planting was conducted from late November to late February. The poles, ranging in length from 1.5 to 5.0 m, were placed in augered holes, and the holes were backfilled with soil. Branches were usually pruned but pole apexes were left intact. Nearly all of the plants were protected from browsing by fencing large planting sites or individual trees. The purpose of this planting method was to have a successful propagation technique that would be less expensive than surface irrigation methods and require little or no follow-up maintenance. Survival of planted cuttings ranged from 0% to 100%, 1 year after planting to 0% to 80%, 4 years after planting. The most successful site was a clay-loam, 24-hectare farm field with a stable ground water table near Percha Diversion Dam, Sierra County. Nearly 1,450 cuttings of cottonwood, willow, and hybrid poplar genotypes were planted in the Percha field during the winter of 1985-1986. Survival in September of 1987 and 1988 was 83% and 82%, respectively. During the growing season, the depth of ground water ranged from 0.45 to 1.5 m, and ground water salinity ranged from 0.12 to 0.18 S/m at an average pH of 7.6. Much of the tree loss and poor growth was in the northwest portion of the field where average soil salinity (0.64 S/m) was four times greater than the rest of the field (0.16 S/m). Visual observations of the 13 sites indicated growth vigor or survival was apparently reduced by excessive salinity, prolonged inundation, shallow ground water depths (<0.3 m), browsing, weed competition, and defoliation by grasshoppers. The average planting cost at the Percha field was $12/pole, 75% less than the cost of $48/pole for sites that required fencing of individual poles. Successful establishment was associated with (1) taking and planting dormant cuttings (1-3 years in age) in the winter prior to mid-February, (2) placing the distal ends of cuttings in ground water which was available during the entire growing season (fluctuation of ground water surface should be measured for at least 1 year prior to planting), (3) keeping poles from drying, even slightly, before planting (soaking cut ends prior to planting may be helpful), (4) avoiding sites with moderate or high salinity, salt accumulation on the ground surface, very shallow depths to ground water, and, except in the case of willow, growing-season long inundation, and (5) fencing and screening to exclude cattle, lagomorphs, and beaver *Castor canadensis*. Future reservoir flood plain revegetation should be directed toward selecting and propagating ecotypes of willow and other species that can survive more than one growing season of inundation and become a seed source to revegetate moist riparian sites following reservoir drawdowns and receding river overflows of stream banks.

Streambank Stabilization In Strawberry Valley, Utah

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Abstract.—In 1984, a pilot riparian rehabilitation project was undertaken by the U. S. Bureau of Reclamation and the U. S. Forest Service in Strawberry Valley, Wasatch County, Utah. The objective of the project was to stabilize eroding streambanks and restore riparian vegetation along streams that have been degraded over the past 60 years. Funding ($55,000) was provided under the U. S. Bureau of Reclamation Soil and Moisture Conservation program and work was administered by the Uinta National Forest in cooperation with the Utah Division of Wildlife Resources and the U. S. Fish and Wildlife Service. Structural rehabilitation and revegetation measures were completed on 3 km of stream, including portions of Co-op Creek, Clyde Creek, and Strawberry River.

In 1985, a 5-year agreement between the primary agencies was signed. From 1985 through 1988 an average of $70,000/year has been used to stabilize and revegetate more than 16 km of bank on six streams. Three structural stabilization techniques have been widely used. First, aspen logs have been placed at the base of eroding banks to prevent undercutting and subsequent sloughing. The logs are approximately 3 m long and are pinned to the bank using two pieces of 1.6-cm steel rebar 2-m long. Where needed, logs are stacked to accommodate higher flows. When the upstream end of the log cannot be tied into a stable bank, rock rip-rap is used to prevent water from cutting behind the end of the log.

The second technique is to place juniper *Juniperus* spp. trees, with branches attached, on cutbanks to dissipate hydraulic energy and provide sediment traps. The butt end of the tree is anchored in place with a 3-m piece of 1.6-cm rebar, and the top is wired to the butt end of the next tree. In this way, trees are laid along the bank in a shingle effect, providing continuous bank coverage. This method has been the most successful, least labor intensive, and least expensive in meeting the objectives of the program.

Rock rip-rap, used as gully plugs and sediment traps in deep gullies, is the third method used. Trapped sediment provides an excellent seed bed for revegetation efforts, and through the process of raising the water table, the riparian area along the stream will be widened. Structures have been designed to allow fish passage where necessary.

In 1987, fencing was used for the first time to exclude cattle from an area. Approximately 1.5 km of fence was built to protect 2.5 km of stream. Fence maintenance is accomplished through cooperative efforts of all involved agencies and cattle operators. More fencing will be needed in the future.

Revegetation is accomplished with the planting of native willows *Salix* spp. and sedges *Carex* spp. Willow planting involves placement of cuttings, use of rooted stock from nurseries, and placement of entire clumps (moved with a backhoe). All willow stock is obtained in the Strawberry Valley.

Sedges are obtained from patches adjacent to streams. Large pieces of sod picked up with the bucket of a front end loader are placed in shallow water so roots remain moist. The sod is then cut into smaller pieces with shovels and planted behind the stabilization structures.

The project in Strawberry Valley has proven very successful and has been used as a model for other similar projects in the state. Funding is scheduled for several more years, to accomplish work on approximately 80 km of nine streams.

Bear Valley Creek Riparian Pasture: Opportunity for Coordinated Management

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Abstract.—Implementation of the riparian pasture concept was incorporated into the Bear Valley Cattle Allotment on the Salmon National Forest in 1978. The project area consisted of a 25-hectare riparian meadow with a low gradient section of Bear Valley Creek. Environmental analysis indicated that cattle use of the riparian meadow was unacceptable, and that fishery, wildlife, and range values were being negatively impacted. The stream reach within the project area contained extensive spawning habitat for chinook salmon *Oncorhynchus tschawytscha* and anadromous rainbow trout *O. mykiss*. Riparian vegetation within the meadow was dominated by grass Gramineae, sedge *Carex* spp., and forb communities along with a willow *Salix* spp. community; all had been influenced by intensive grazing. The riparian pasture required 1.6 km of fencing to control livestock use within the riparian area. Several angler access points were designed into the fence to reduce the need for gate openings and fence climbing. Cost of the project was approximately $5,000 which included all materials and administration of a small Comprehensive Employment Training Act (CETA) work force. Objectives of the project were to reduce negative influences resulting from intensive cattle use on the riparian area by controlling use levels with a riparian pasture.

Qualitative benefits provided by the riparian pasture included protection of the spawning habitat (specifically spawning gravel condition) and enhancement of the rearing habitat (primarily the amount and quality of streambank cover). Production capabilities for the anadromous species before and after project implementation were also estimated (Table 1). Substrate condition expressed as a percent fines less than 6.3 mm changed from 27% to less than 10% following initiation of the pasture. Streambank stabilities substantially increased, as did the available cover associated with the banks. Several wildlife species also benefitted from the project. As the willow communities condition improved, increased use of the meadow by moose *Alces alces* and elk *Cervus canadensis* was observed. Small game and birds benefitted from the improved cover and increased vegetation growth.

TABLE 1.—Habitat condition and production estimates associated with implementation of a riparian pasture on Bear Valley Creek, east-central Idaho.

	Before	After	Diff.
Habitat condition (% optimum)	50	90-100	+40
Production potential (% optimum)	40-60	90-100	+50
Total biomass (kg)	4,638	9,276	+4,638
Associated user days (WFUD)	449	897	+448
Potential commercial harvest (kg)	1,326	2,651	+1,326
Associated dollars	$30,400	$60,800	$30,400

An unexpected benefit was realized in livestock management as well. Isolation of the riparian meadow has changed cattle distribution patterns by eliminating access to the once preferred site. Cattle use has been reprogrammed to the upland forage areas resulting in more uniform distribution and the livestock permittee is highly supportive of the change because it has simplified heard management and increased animal growth.

The riparian pasture has provided the land manager with a viable tool whereby the forage resource can be utilized by livestock without causing unacceptable influences on other resources. Riparian areas can be managed to provide forage for livestock as well as quality habitat for fish and wildlife if all resources are considered during planning and the subsequent administration of grazing activities.

New Approaches to Riparian Area Management on Public Lands

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Abstract.—Riparian areas are among the most productive ecosystems found on the 109 million hectares of public lands managed by the U. S. Bureau of Land Management (BLM). Because of the importance of riparian areas, conflicts have arisen among a variety of special interests over what is considered appropriate riparian management. In some cases, these areas have become battlegrounds with conservation groups seeking protection and preservation and other user groups desiring continued use of these productive areas.

The BLM managers are attempting to resolve these conflicts in such a manner that the natural resource values of riparian areas are protected yet used to best advantage on a sustained yield basis. To accomplish this, BLM emphasizes a multidisciplinary approach to riparian management, involving not only the traditional programs, such as wildlife habitat management and soil, water, and air management, but also minerals, grazing, forestry, recreation, lands, and others.

This multidiscipline approach to riparian management has evolved over two decades. In the 1960s, it became widely recognized that certain logging practices, such as leaving debris in streams, yarding logs through streams, and road building, had detrimental impacts on fish habitats. Many of the streams affected were highly valuable salmon *Oncorhynchus* spp. and steelhead *Oncorhynchus mykiss* streams. After a period of confrontation, biologists, foresters, and other resource specialists began to look for ways to accommodate both logging and fisheries. Today, protecting riparian and fisheries values in BLM forests is a matter of routine practice.

The multidiscipline approach to riparian areas in more arid western rangelands is evolving in much the same way. During the 1970s, some BLM resource specialists began conducting inventories to determine the condition of riparian habitats and recommended measures to maintain, restore, or improve important areas. Many riparian areas were found to be in less than desirable condition. At the same time, research was documenting the detrimental impacts of excessive livestock grazing on streams and associated fish and wildlife habitats, and water quality and quantity. The BLM managers responded to growing concern for proper riparian management by excluding all livestock from a few highly valuable areas. These riparian exclosures were an important step in demonstrating the resiliency of riparian systems which can be restored to health in a relatively short period of time.

Recognizing that costs of construction and maintenance render fencing every riparian area impractical and that livestock grazing and proper riparian management can be compatible, BLM managers are now turning to grazing strategies that consider the needs of livestock and the requirements for healthy riparian systems. Range conservationists, biologists, and other resource specialists work with livestock operators to design grazing systems that reduce or eliminate livestock use from pastures containing important riparian areas during the hot summer months, when most damage occurs. Livestock often "camp" on riparian areas in hot weather, seeking water, shade, and succulent forage. By allowing livestock into riparian pastures primarily during the early spring, late fall, or winter, better utilization and protection of the area can be achieved. Increasingly, not just the riparian zone but the entire watershed, including the uplands, are considered when designing grazing strategies. Successes applying the riparian pasture concept have been documented in Colorado, Oregon, Idaho, Wyoming, and Montana where a variety of grazing strategies have been used to achieve riparian habitat recovery.

The BLM Director has recently signed riparian policy statement that emphasizes the multiple values and multiprogram responsibilities for riparian management. One key statement of the BLM's riparian policy directs managers to recognize the importance of riparian values in resource management and activity plans and to initiate actions to maintain, restore, or improve them. Thus, strategies for sound riparian management are now being included in grazing allotment management plans, timber management plans, mining operation stipulations, and other activity plans. The riparian policy also gives special attention to monitoring and evaluating management activities in riparian areas and to revising management practices where site-specific objectives are not being met. Resource specialists use a variety of techniques, including photo plots, vegetation transects, low level aerial photography, and aquatic insect sampling, to determine the health of riparian systems. This information is used to advise managers on the effectiveness of land use and activity plans and to recommend where changes in management strategies are needed.

To illustrate the enhancement of riparian areas, the BLM Director has required that each field office develop at least one riparian demonstration area, where the best management practices and instream habitat improvement work have been or will be implemented. These areas will demonstrate the benefits and resiliency of riparian systems to BLM resource specialists and managers, livestock operators, conservation groups and other public land users.

The BLM is involved in acquiring new and critical riparian areas through land exchanges with State and private owners. In Arizona, more than 63,500 hectares of pristine riparian habitat were acquired during the last 2 years. In the California Desert, BLM, the Nature Conservancy, and San Bernadino County developed and maintain a wildlife sanctuary in Big Morongo Canyon.

Maintaining and improving riparian areas requires the help of all users of the public lands. The BLM encourages involvement of public groups in projects, such as the construction of gabions, planting trees and shrubs along streams and reservoirs, and assisting in monitoring and study efforts. Conservation organizations are assisting the

BLM develop on-the-ground projects by matching Federal Challenge Cost Share funds with volunteer labor and/or contributed funds.

The BLM now recognizes the multiple values of healthy riparian systems and is beginning to employ effective management approaches to preserve these values. This progress will continue through multidiscipline efforts that involve BLM resource specialist and managers, livestock operators, conservation organizations, State and Federal agencies, sportsmen, and other interested in restoring and enhancing riparian areas on public lands.

The Fort Stanton Riparian Demonstration Project

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Abstract.—The ability to gain support and confidence of public land users for the U. S. Bureau of Land Management emphasis on the maintenance, restoration or improvement riparian areas can best be accomplished through demonstration projects. The Rio Bonito and Salado Creek Riparian Demonstration Project areas, located at Ft. Stanton Reservation in south-central New Mexico, typify streams in the pinon *Pinus* spp.-juniper *Juniperus* spp. habitat. Techniques utilized to enhance in these areas include protective fencing, experimental tree plantings, streambank stabilization, and the use of volunteers to construct habitat improvement projects.

Three exclosures were constructed on the Rio Bonito during the summer of 1983, and photopoints were established and monitored annually during July. Of the three exclosures, Government Springs Exclosure has displayed the most dramatic natural stream alterations created through flooding and protection from livestock. In many sections of the stream the water channel had shifted from one side to the other, bank stabilization with heavy grass and dense stands of willow *Salix* spp. has occurred, encroachment of vegetation on exposed gravel bars and establishment of aquatic vegetation has been observed, and the area receives use by various songbirds, waterfowl and mule deer *Odocoileus* sp.

The Salado Creek Riparian Demonstration Project Area was established in 1987 to determine the feasibility of enhancing the Salado Creek riparian area which, at the time of selection, did not support native riparian vegetation. An 81-hectare exclosure was constructed to protect a section of the stream from livestock use and to protect experimental tree plantings. Observation wells were established to determine monthly water table fluctuations, soil samples were analyzed for pH level, salinity and mineral composition, and water samples were analyzed for pH level and dissolved solids. Native cottonwood *Populus* spp. and willows were planted at various depths and distances from the stream along with hybrid poplars *Populus* spp. donated by the Soil Conservation Service. Photopoints were established to document changes in the riparian area. Ninety percent of the trees and 75% of the willow cuttings survived. Dramatic improvement of the streambank has been observed along with the establishment of cattails *Typha* spp. and sedges *Carex* spp. within the exclosure.

The demonstration projects have increased our knowledge about the physical and biological characteristics and potentials of the riparian community. The techniques have application to future management of riparian areas and will promote public awareness and participation in riparian area management.

Riparian Vegetation, Streambank Stability, and Land Use in the Salmon River Drainage, Idaho

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Abstract.—The Bonneville Power Adminstration and an interagency technical committee contracted a study to inventory the riparian and aquatic habitats of the upper drainages of the Salmon River in Idaho, which are important spawning grounds for chinook salmon and steelhead trout (OEA Research 1986). Two study areas were identified based on differences in geology, geomorphology, and land use patterns. The Upper Salmon River (USR) study area encompassed the main stem and selected tributaries to the Salmon River above the confluence with Valley Creek, and Valley Creek and four of its tributaries. The Middle Fork of the Salmon River (MF) study area encompassed the drainages of Marsh and Bear Valley creeks and 12 of their tributaries. These two headwater drainages join to form the Middle Fork of the Salmon River.

The portion of the study that addressed interactions among streambank stability, riparian vegetation, and land use emphasized the impacts of livestock grazing. We attempted to answer three specific questions:

(1) Is streambank stability affected by the riparian community type present?

(2) Is streambank stability affected by type and intensity of grazing use?

(3) Is streambank stability differentially affected by community types exposed to different grazing uses?

Riparian corridor data collected during the summer of 1985 and grazing use data provided by the U. S. Forest Service, which administers grazing leases in the study areas, were used in the analysis. Riparian plant community types (Whitehorse Associates 1982) were identified by performing continuous bank transects on low gradient streams and subsequently delineated on aerial photos. Within each identified type, bank stability was evaluated and estimated in meters by category (stable, depositional, or cut/slough). Grazing use delineations (called subreaches) were marked on the photos after all field data were collected. Four categories, based on streamside use from 1983 through 1985, were used:

(1) heavy cattle grazing — greater than 55% grass and forb utilization.

(2) moderate cattle grazing — less than 55% grass and forb utilization.

(3) sheep grazing — any sheep grazing.

(4) little or no use — little or no grazing of any sort, although grazing may have occurred prior to 1983.

A two-factor factorial experiment in a two-way classification Analysis of Variance (ANOVA) with replications (unbalanced design) was set-up to test the above stated hypotheses. Community type (CT) and grazing use (GRZM) were the independent (class) variables. The dependent variable, bank stability, was represented by the community type stability index (CTSI). This number was calculated as the amount of stable bank by community type within a subreach. For the USR study area, 10 community types were used in the analysis, while in the MF study area, 7 types were used.

Summaries for the effects of community type and grazing use on streambank stability show that in both the USR and MF study areas, there is insufficient evidence ($P<0.47$ and $P<0.87$, respectively) to reject the null hypothesis that there is no interaction effect between grazing use and community type (Table 1). That is, differences among mean bank stabilities within each community type are similarly affected by different types and intensities of grazing use, as defined in these studies.

Table 1.—Analysis of variance summary for the Upper Salmon River and Middle Fork study areas. Tests are significant at $P<0.01$.

Model:

Dependent variable: community type stability index (CTSI);

Independent variables: community type (CT) and grazing use (GRZM)

Upper Main Salmon Study Area

Source	df	F-value	$P>F$
Model	39	22.77	0.0
GRZM	3	15.45	0.0001
CT	9	90.55	0.0
GRZM*CT	27	1.00	0.472
Error	1009		
Corrected Total	1048		

Middle Fork Study Area

Source	df	F-value	$P>F$
Model	27	50.5	20.0
GRZM	3	11.44	0.0
CT	6	219.70	0.0
GRZM*CT	18	0.63	0.8742
Error	677		
Corrected Total	704		

Results suggest that there are no significant differences among CTSI means for each main effect ($P<0.01$). The Tukey-Kramer method for multiple comparisons was used to determine which CTSI means were significantly different.

Taken together, these results suggest that regardless of the community type growing on the streambank, heavy cattle grazing and, to some extent moderate cattle grazing, decreases bank stability. Sheep grazing on the other hand, has a minimal destabilizing effect.

It appears that streambanks within xeric community types, such as thick-stemmed aster *Aster integrifolius/*

Idaho fescue *Festuca idahoensis* and shrubby cinquefoil *Potentilla fruticosa*/timber oatgrass *Danthonia intermedia* are inherently much less stable than banks occupied by hydric or mesic types. Hydric types, such as willow *Salix* spp./beaked sedge *Carex rostrata*, Wolf's willow *Salix wolfii*/swertia, and beaked sedge are associated with the most stable banks. Kentucky bluegrass *Poa pratensis*, a mesic type, acts more like a xeric type. Drummond willow *Salix drummondiana*/bluejoint reedgrass *Calamagrostis canadensis*, a mesic type, acts more like a hydric type.

Differences in soil type are likely to account for these differences in inherent bank stability. Soils associated with the xeric communities are, by definition, droughty and are composed of cohesionless sands, gravel, and cobbles. They are very susceptible to erosive forces. Soils associated with hydric communities have well-developed sod surfaces that act as a protective cap to the more erodible channel materials. This sod cap, which is subjected to erosive forces, is, in turn, highly resistant to them. Also, vegetation tends to overhang the banks and provides additional protection.

Streambanks subjected to heavy cattle grazing, as defined here, are more unstable than banks grazed moderately or those grazed by sheep. Bank stability differences were not detectable between sheep and no grazing or between sheep and moderate cattle grazing. Herding methods may account for the apparent differences.

All community types showed a progressive decline in bank stability with increasing grazing use. Although field observations indicated that different community types respond differently to grazing use intensities, the analysis did not detect this.

The proposed model did account for a large percentage of the variation in streambank stability in both study areas, but as such, the model only identified part of the relationship. Examination of the error statements suggest that further testing utilizing data transformations or non-linear models is warranted.

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Response of Mountain Stream Channels and Associated Riparian Areas to Flow Regulation

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Abstract.—The need for channel maintenance flow releases below water development projects in the central Rocky Mountain region is currently being debated. The objective of our study was to measure the change in hydraulic geometry of mountain stream channels in response to water diversion. Channel width, depth, width to depth ratio, cross-sectional area, and conveyance capacity were measured above and below diversion structures on 20 stream reaches in Wyoming and Colorado to determine the extent of channel adjustment since regulation. Ocular estimates of riparian vegetation density were also made. Diversion structures ranged in age from 12 to 106 years and reduced streamflow up to 90%.

Our preliminary analysis using paired *t*-tests indicates no significant ($P > 0.05$) differences in channel dimensions above and below diversions on steep (slope > 4.0%) and moderate (slope 1.5 to 4.0%) gradient channels. Low gradient (slope < 1.5%) channels responded to streamflow depletion by significantly reducing their depth, area, and conveyance capacity. In a majority of cases, we observed no differences in vegetation density above and below diversion structures.

Our preliminary results indicate that moderate to high gradient mountain stream channels located in the forest snowpack zone may be maintained with reduced streamflow regimes. Low gradient channels, where encroachment and aggradation appear more likely to occur, should be the primary focus of channel maintenance flow studies.

Bebbs Willow Seedling Establishment in Shade

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Abstract.—Although willows *Salix* spp. are used as a diagnostic tool for riparian management, their life cycles have been poorly documented. Because there are 36 species of willow in Montana (Dorn 1986), the genus *Salix* should not be relied on as an indicator of the status of a riparian community. Without a specific epithet, *Salix* is inadequate for the complex tasks of classifying communities, determining site potential, and managing riparian zones. Traditional assumptions about members of the genus *Salix* being pioneers or colonizers must be viewed with skepticism; only recently have land managers, biologists, fisheries ecologists, and others concerned with riparian management identified willows to the species level. The variety of willow community types and willow associations should emphasize the need for documenting species' life cycles in riparian research.

Salix bebbiana, used in this study, is widespread in North America and is abundant along streams, lakes, and swamps, as well as open hillsides, meadows, and forest margins (Froiland 1962). Averaging 5-6 m, Bebb's willow provides instream fisheries cover, habitat for passerines and ground dwelling birds, shade and browse for both livestock and wildlife, and streambank stability. Bebb's willow also serves as a corridor for wildlife movement along ephemeral and perennial streams in arid regions.

Bebb's willow is thought to reproduce primarily by seed (R. Dorn, Wyoming Department of Environmental Quality personal communication), however, the shrub also suckers, growing from buried stems and stumps. Although Bebb's willow may live to 60 years of age, decadence and loss of vigor can be found in all age classes. Unhealthy stands of Bebb's willow, composed of individuals with dead stems and loss of canopy coverage, have been documented in the Black Hills (Froiland 1962) and in SW Montana (Dorn 1970). These decadent communities do not appear to recruit new individuals, which may indicate a change in land management or a shift in ecological status. Decline without replacement has been observed (Froiland 1962; Atchley and Marlow unpublished data); however, it is not known if this decline is an expected stage of riparian succession or a stage caused by altered waterflows and loss of conditions for establishment. The specific objective of our investigation was to determine if Bebb's willow could establish under low light intensities.

Seeds harvested and stored as recommended by Densmore and Zasada (1983), were germinated on blotters soaked with 100% Hoagland's solution, and allowed to grow for 10 d. Germination was under a cycle of 16 h light, 8 h dark, with corresponding temperatures of 15°C and 25°C.

Growth chamber light intensity was adjusted to 630 umol/s/m^2, or about 30% of full sunlight (fs); 30% fs was the highest light intensity to which the seedlings were exposed. Single to multiple layers of plastic and cotton screens were used to provide 10%, 3%, and 1% fs. A tray containing 18 pots, planted with one Bebb's willow seedling per pot, was one replication. There were three replications at each light intensity. Seedlings were planted in a silt loam and subirrigated every 2-3 d to maintain a moist soil. Seedlings were watered with 100% Hoagland's solution to maintain soil fertility. The growth chamber provided a cooling system that kept all replications within ±3°C of the daytime temperature of 25°C. Temperature and hours of light were maintained at the levels used during seed germination. Sixty days after planting, leaves were counted, and roots and shoots were harvested, measured for length, oven-dried at 30°C for 3 d, and weighed to the nearest 0.1 mg. Establishment in this experiment was defined as root and shoot growth past the first-leaf stage. A live seedling with two or more leaves at day 60 was considered established.

All of the 1% fs seedlings died by day 30. Plants under 30% fs produced significantly less shoot biomass than the 10% fs plants when tested with ANOVA (Table 1). The 10% fs plants produced twice as much shoot to root material within that treatment. Mortality in the 30% fs group occurred in the first 30 d. The 3% fs plants died throughout the 60-d period. No mortality occurred in the 10% treatment.

Table 1.—Mean dry weights of roots and shoots grown under three light intensities measured as percent full sunlight (fs). Columns with the same letter are not significantly different ($P > 0.05$).

fs %	Root weight (g)	Shoot weight (g)	% established 60 d	Root/shoot
30	0.1644a	0.1474a	72	1:1
10	0.1182a	0.2226b	100	1:2
3	0.0054b	0.0004c	44	13:1

Plants under 30% fs developed thick, green leathery leaves with red spreading from the midvein. These plants typically were 3-8 cm in height. The 10% fs plants grew only green, supple etiolated leaves on elongated stems, 10-16 cm in height. The number of leaves from 30% and 10% fs were not significantly different ($P<0.05$). Despite similar leaf numbers, the stem production under 10% fs was greater than under 30% fs; this accounts for the higher mean shoot weight of the 10% fs plants. At 3% fs, plants remained stunted and rarely produced more than four small leaves, indicating they did not morphologically adapt to low light intensities.

The soil surface in a closed turf community like a Carex bog receives 5% fs. Forest floors receive approximately 2% fs (Larcher 1981). Shade tolerant species under closed canopies maintain positive assimilation rates with low saturation points and low respiration levels (Grime 1965). Morphological changes are characteristic of shade intolerant species (Fenner 1978) and were observed in Bebb's willow under 10% fs. The 10% fs plants responded to shade by producing elongate, pliable stems, and etiolated leaves. Fenner (1978) found that mean weights of colonizer species were lower than shade tolerant species under 6.8% fs. The response of Bebb's willow under 3% fs and the 100% mortality at 1% fs suggests an intolerance to low light levels at the seedling establishment stage. This is supported by the low shoot development (root/shoot ratio of 13:1) under 3% fs.

Light intensities at 10% fs are common throughout riparian zones in time and space. The edges of streams, springs, rivers, lakes or marshes could provide windows of light near or above 10% fs. The dynamic nature of riparian zones, fluctuating water levels, scouring of channels, depositing silt, cutting channels, and overspilling of banks alter the landscape and plant communities sufficiently to change site conditions and light availability. Apparently, light intensities greater than 10% fs are more conducive for establishing Bebb's willow than the lower intensities under riparian forest canopies and closed turf grassland communities.

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The Effects of Renovation of Fleshman Creek in Livingston, Montana

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Abstract.—The water chemistry, morphology, and trout populations in sections of Fleshman Creek were studied to determine the effects of renovation. Prior to renovation, water from Fleshman Creek flowed through all study sections. After renovation, the lower two study sections were fed water from the Yellowstone River through a gravity flow pipeline. Increases in average dissolved oxygen concentration, temperature, and pH were documented after rehabilitation, but turbidity, conductivity, alkalinity, and hardness decreased. Physical alterations of the Enterprise section resulted in decreases in average channel width, average water depth, and total cover, and increases in sinuosity and average current velocity. Streambanks were seeded with a mixture of grasses and planted with willow shoots to facilitate bank stabilization and development of cover. Prior to renovation an estimated 67 (+/- 13) brown trout *Salmo trutta* occupied the section. Only four small brown trout were captured during electrofishing the first year after renovation. Subsequent population estimates document the growth and changes of the population. Before rehabilitation, age-II and -III and older brown trout comprised 92% of the population. Post-rehabilitation estimates have shown age-I fish to comprise up to 85% of the population.

The St. Mary's section of the stream was not physically altered but did receive water from the new source. Mean depth, mean current velocity, and cover all increased as a result of increased discharge after renovation. Age-I fish comprised 57% of the brown trout population in the St. Mary' section before rehabilitation and up to 90% since.

Rainbow trout *Oncorhynchus mykiss* populations were too low in both sections to estimate prior to renovation but have since increased to measureable levels. Estimates of rainbow trout in both study sections are confounded by the possible influence of hatchery reared fish that are periodically stocked in a small lake at the upper end of the stream.

The Use of Prescribed Fire Within Interior West Riparian Ecosystems

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Abstract.—Fire has historically been a key environmental factor influencing the structural and compositional diversity of all western plant communities. The successful suppression of wildfires over at least the last 80 years and a lack of prescribed burning have aided the vegetations trend toward late successional communities. The use of prescribed fire to manage riparian areas is not new but is little practiced in the Intermountain West. The increased extent of the vegetation approaching a climax condition has impacted the principal land management goals of increased livestock forage, improved wildlife habitat, and higher quality timber. This paper presents the generalized role of fire within major classifications of riparian communities. Reasons are presented why prescribed fire has been limited in the past and how the use of new prescribed fire strategies and technologies are starting to increase the application of prescribed fire to improve resource values in and adjacent to, riparian ecosystems.

Effects of Phased Highway Improvements, Browsing and Moisture Stress on the Riparian Ecosystem Along the Upper Gallatin River, Montana

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Abstract.—Woody riparian vegetation along the upper Gallatin River in Gallatin County, Montana, at approximately 2,130 m elevation, has become sparse over the past 60 years. This change has been attributed to winter browsing by an over population of elk and was used, in the 1960s, to justify a reduction in elk numbers in this area. Historical photographs from the 1920s, 1940s, 1960s, and 1980s show these changes, primarily loss of most riparian willows. With the use of these historical photographs and aerial photographs dating back to the 1940s, stream channels are shown to have changed many times over the past few decades. Aerial photographs and county highway records also show that there have been highway improvements in the study area in the 1930s, 1950s, and 1980s. These improvements, which include use of rocks and fill to allow widening of the highway into the river valley, have caused increasing constriction of the stream channel, resulting in increased sediment deposition and stream channel changes above the constriction.

The sediment deposition and changes in stream channel morphology have either buried or disrupted the willow community. The nearly 1-m deep sediments have created an environment of fine soils with a soil surface well above stream flow that is inhospitable to willow growth and regeneration. Willow regeneration now occurs only where old river gravels are being exposed as stream channels that have cut through the sediment are abandoned as a result of channel shifts. Multiple regression analysis of willow cover with environmental factors shows height above stream as the primary variable explaining the variation in willow cover with surface texture (rockiness) the most common second variable.

Browsing by elk occurs throughout the willow community. Young willows in the abandoned stream channels may be stunted by browsing; however, they show little loss of vigor. On the other hand, mortality of browsed branches or whole plants of mature willows is a function of distance from the river or height above the stream, both environmental conditions that may create moisture stress. Soil moisture has been shown to decrease rapidly between 10 and 30 m from the stream (Patten 1968). *Salix exigua*, which occurs near the stream, shows fewer effects of browsing than *Salix lutea*, which is more common away from the stream.

The riparian and non-riparian vegetation mosaic along the upper Gallatin River is thus a result of the combined effects of sedimentation, browsing, and moisture stress. Of these factors, increased deposition of sediments due to highway improvements is the easiest to control. Highway planning along streams should take into consideration impacts on fluvial processes and how changes may affect the dynamics of the riparian community.

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Use of Channel Types to Monitor Debris in Salmon Streams of Southeast Alaska

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Abstract.—The Tongass National Forest is the largest forest in the USA. It comprises 6.72 million hectares dispersed throughout southeast Alaska and contains 32,398 km of streams. To adequately manage the complex water resources on the Tongass National Forest, the U. S. Forest Service has developed a channel-type classification system to inventory the stream resource.

The classification system has two categories: the channel-type association, containing the entire population of streams within six broad classes, and the specific channel types within the associations. The six channel associations are: water/sediment source (A type), water/sediment transport (B type), water/sediment deposition (C type), glacial influence (D type), estuarine intertidal (E type), and placid, slow moving waters (L type).

Channel types are identified on color aerial photographs (1:15,840 scale) under stereoscopic examination. Seven primary criteria are used for mapping differentia. These criteria are: (1) channel gradient, (2) width, (3) incision depth, (4) drainage basin area, (5) adjacent land form, (6) riparian vegetation class, and (7) channel patterns.

The channel-type classification system was designed to describe structure of and relationships between similar stream components, and therefore it is useful for grouping sample sites for representative data sampling from different watersheds. In 1986, the Alaska Department of Fish and Game, Commercial Fisheries Division, studied channel types within 10 watersheds. The objective of the study was to determine if coho salmon (*Oncorhynchus kisutch*) could be used as an indicator of the presence of anadromous species and thereby extend documentation of streams that support anadromous fishes. If a 30% probability of the presence of coho salmon rearing habitat in certain channel types was assummed, the portions of these streams that were mapped as salmon habitat could be increased by 60% in the study area.

Observations of riparian vegetation classes were consistent within the channel-type sample site when compared to the original classification of the channel type made by photo interpretation. The use of channel type as a management unit could facilitate planning for vegetative leave areas within the riparian zone because it is readily identified on aerial photography.

The various channel types were sampled to determine the porportion of channel surface area covered with large woody debris, but sample data were too variable to describe an average debris load by channel type. Refinement of study design and methods of measuring large woody debris are needed to accurately characterize the existing amount of such debris occurring in different channel types. The homogeneous nature of a channel type should provide the appropriate sample site to monitor changes in woody debris within channels if adequate sampling methods can be developed.

Channel-type maps can be a useful tool to apportion vegetative leave areas along streams if they are related to the physical evaluation of the individual channel-type characteristics. Management concerns for fish habitat maintenance can be addressed only after the quantity and quality of woody debris that affect fish production are known.

Using Expert Systems in Riparian Management

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Abstract.—Perhaps the most expensive and devastating resource losses among the land management profession is the loss of on-the-ground experts through relocation, retirement, promotion, and death. How many experts go through their careers with their knowledge locked inside of them, or worse, with what little documentation they did produce ending up in the archives or trash? The expert system provides a way not only to retard this knowledge loss but to place the knowledge into immediate use whenever it is relevant. The U. S. Bureau of Land Management in Idaho has begun a project to develop knowledge based expert systems for riparian management. The objectives of the project are to provide a means for the riparian expert to store knowledge of management outcomes, to help others apply the knowledge to other areas, and to help in selecting appropriate monitoring techniques.

Three related expert systems are being constructed. One expert system will be designed to capture knowledge of riparian area experts on the causes and effects from various management actions. A second expert system will be designed to link the management outcomes to various riparian area types as defined by classification. A third expert system will be designed to help a user select relevant monitoring techniques for their particular area and management objectives.

Classification is used to place riparian habitats into categories or groups of similar features. Typical biological features used include dominant overstory and understory vegetation species, age distribution, and associated fish and wildlife. Physical features include description of geology, land type, soils, water regime, and stream morphology. Many of the latest riparian/wetland classification documents are merging physical and biological features into site descriptions named for the dominant vegetation species.

The classification expert system uses knowledge of features to arrive at the probable classified group or groups based on published classification. Additionally the expert system contains information on dominant processes that are used to link the classification to the management response and monitoring expert system. The user is asked for information on vegetation and physical features. Questions are answered if there is information, otherwise the expert system assumes an answer. The expert system then applies the input information to pertinent rules and selects the most likely choices for the name of the site is selected on the basis of published classification documents. Appropriate notes and references are supplied to give the use additional information.

Information is collected from riparian area experts in the form of a questionnaire that identifies observed cause and effect, site features corresponding to those used in the classification expert system, and other information having to do with quality assurance. These data are reviewed by appropriate vegetation, hydrology, and geomorphology specialists and entered into the management-response knowledge base. We hope that as sufficient information is developed, similar cause-and-effect observations will emerge, providing a type of replication to what otherwise would remain untested, provisional cause and effect relationships.

The management response expert system provides an easy means of documenting field observation of cause-and-effect and should help increase the on-the-ground capabilities of management. The management response expert system operates similarly to the classification expert system. Pertinent questions are asked to define important processes in the riparian area and the type of management response desired or action being considered. The expert system provides output of all appropriate cause and effect observations related to the user's question with comments on data quality and references. Information on probable effects are given and stored for use in the monitoring expert system.

The monitoring expert system contains reference to monitoring techniques of many different riparian attributes including water quality, vegetation, and geomorphology. The knowledge base contains identification of the attribute to be monitored, precision, accuracy, time requirements in data collection and analysis, difficulty in training, and applicability to management objectives. The user provides information about the site (or it is passed from the other expert systems), on the activity, and basic constraints of monitoring accuracy, time, manpower, and training. The monitoring expert system provides a list of the recommended attribute(s) to be monitored techniques that best suit the objectives and constraints.

Once linked, these three expert systems will provide the riparian manager with access to a large amount of knowledge. The advantage of the expert system is that it only provides information that is pertinent to the problem or question.

Interpretation of Exclosures in Riparian Vegetation

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Abstract.—Exclosures are erected to asses the effects of large ungulates on the vegetation of an area. Transects are established when the exclosures are built, and the cover and species of plants recorded. The expectations, in a heavily grazed area, are that the more palatable plants, sensitive to grazing or browsing would decrease and those less palatable would take their place. Exclosures would allow the species to regain their ungrazed relationships. Implicitly assumed in these expectations is that sensitive plants would die and those less palatable would be able to establish in the sites left empty. This is usually taken as a sign of over-grazing.

Many managers also assume that the desired vegetation is the climatic climax vegetation of a site as indicated by that growing on sites that have been free from large ungulates. Long standing exclosures are often used as bench marks that indicate the "desired" vegetation. Any departure from this vegetation is considered signs of overgrazing and prima facie evidence of something wrong or that man has thrown nature out of balance. Assumptions are also made that on ecotones the sensitive plants would disappear first from the margins of their occupied area and then finally eliminated even from the optimal portions. If the ungulate influence were released or reduced to "proper" levels the sensitive plants would move back into the marginal portions of the ecotone.

Some observers are tempted to compare the inside and outside transects and attribute all the difference to ungulate effects. This, however, is not the intent of exclosures and is invalid because there are obvious and subtle site differences that affect the plant response. Ungulate effects are shown by differences revealed over time as the transects are remeasured.

In Yellowstone National Park, six exclosures were built that included riparian vegetation. Three were built in 1957 or 1958 and three were built in 1962. Not one of them was along a stream; all were in seep areas where enough ground water reached the surface to allow willows *Salix* spp. and other wetland vegetation to survive. Transects that measured 33-m long and 1.5-m wide were established and measured both inside and outside the exclosures. Willows in each transect were measured for height, and the cover recorded on transect maps. Transects on the inside were placed on ecotones with one end in established willows and the other end free of willows and tending toward upland vegetation. These transects allow us to test some of the assumptions of exclosures as they relate to riparian vegetation. They were remeasured in 1962, 1965, 1974, and 1981. Cover and height of willows has increased dramatically inside the exclosures, and the visual impact is impressive. The inside appears choked with willows 3-m or taller, and the area outside the exclosure appears to be about the same as when the exclosure was built.

Closer examination of the transect maps, however, reveals that the obvious interpretations are not necessarily the correct ones. Cover and height have indeed increased inside the exclosure, but it is all from plants that were on the site before the exclosure was built. There has been no establishment of new willow plants along the transect and no movement into the marginal portions of the ecotone. On the outside, the original willow clumps are still there and are still severely browsed. Both cover and height have increased and decreased in response to the weather cycles. The growth forms of the plants are different. Inside the exclosures the plants have nearly all adult branches, but outside the shoots are predominantly juvenile.

Several conclusions can be drawn from these observations. The willows are obviously able to tolerate long periods of severe browsing without being eliminated from the site. The lesser root biomass observed by some in hedged willow stands may not be an indication of a trend to zero but merely an adjustment to a biomass that a reduced leaf area can support. The failure to establish new plants would indicate that the sites are not longer places where willows can establish. The present willows established when the site was in a different condition. These willow species can be seen establishing on wet mineral soils in other parts of the range, indicating a possible pioneering role. It may be that the willows we see today with a sedge *Carex* spp. understory are long lived relicts of a pioneering successional stage. Complete protection for hundreds of years would not increase the number of willow plants on these sites unless a disturbance would recreate establishment conditions. Given the nature of wetland vegetation it would take a major disturbance. The tall, dense canopy of the enclosed stands creates an entirely different environment that could harbor a different suite of understory plant, animal, and insect species. Species that require full sun would be reduced and possibly eliminated including shorter species of willow. Height of willows can determine their effect on stream dynamics. Streams flowing through a protected stand may have different characteristics than one through a severely browsed stand.

Management of riparian sites depends on the "desired" vegetation. The desired vegetation on any site depends on the management objectives for that site. If a natural system is desired and that system contains large ungulates, a severely browsed stand may be appropriate. Such stands may help us understand the full effects of our management on other lands.

Historical Implications of the Railroad Crosstie Industry on Current Riparian and Stream Habitat Management in the Central Rocky Mountains

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Abstract.—Rivers and streams have historically been used to transport forest products in many parts of the United States. As the railroad pushed into the Central Rockies during the late 1860s, the need for crossties necessitated the use of many streams as conduits to move timber from the forests to the railheads. While documentation of these "tie drivers" is quite extensive, little research has been done relating their influence on stream and riparian habitats in this region to current resource management activities. The objectives of our paper are to (1) summarize the magnitude and extent of the drives in the Central Rockies, (2) describe their effects on river corridors, and, (3) discuss briefly a planned restoration effort for a driven stream located on the Medicine Bow National Forest of southeast Wyoming.

Between 1868 and 1945, millions of railroad crossties, sawlogs, and mine props were cut and transported down major rivers and their tributaries in Wyoming, Utah, and Colorado. Early reports from the Medicine Bow National Forest estimate that over 75,000 m^3 of timber were harvested from that Forest alone between 1860 and 1910. Given the absence of motorized vehicles and developed roads during that period, much of that total was moved by water.

As the Union Pacific Railroad moved across southern Wyoming and northeast Utah in the late 1860s, the first forests cut were in the Laramie, Medicine Bow, and Uinta mountain ranges. Later, with the construction of spur lines, new railroads, and improved transportation routes, extensive timber resources were also exploited in the Sierra Madre, Wind River, and Big Horn ranges. Streams tie-driven included the Little and Big Laramie rivers, Rock Creek, Medicine Bow River, North Platte River, Green River, the Black's Fork, Wind River, Tongue River, Bear River, Henry's Fork, Cottonwood Creek, Mill Creek, and the Smith's Fork.

In Colorado, the east slope provided the majority of forest products for the developing cities of Denver, Fort Collins, Boulder, Colorado Springs, and Pueblo, while on the west slope, tie, mine prop, and cordwood activities were commonplace as development occurred. Major streams supporting tie-drives included those between the Poudre on the north, the Apishapa on the south, and the Taylor in the western part of the State. The drives varied in length from a few kilometers to well over 320 km and occurred frequently on the Poudre, Big Thompson, St. Vrain, South Platte, and Arkansas rivers, and Boulder Creek.

Tie drives were carried out during high water periods of spring snowmelt runoff, usually May or June. The ties were hewn in the woods during the fall and winter and decked along streams awaiting the spring thaw. To facilitate the drives, flumes and splash dams were often built. Also, "stream improvements" were made to assure a swift trip downstream. Common practices included blocking off sloughs, swamps, low meadows, and banks along wider sections with log cribbing to keep the mix of water and logs in the main channel, and blasting or removing boulders, logs, debris, and encroaching riparian vegetation to prevent jams. Frequently, small low-gradient streams were substantially widened as a result of the frequent flushing by the splash dams and the impact of logs on streambanks. The overall implications to fish habitat are apparent.

Douglas Creek is a moderate sized, brown trout *Salmo trutta* stream that was tie-driven for many years prior to 1945. Given its popularity with anglers, its accessibility, and an augmented low flow regime due to water development, the Medicine Bow National Forest selected Douglas Creek for habitat evaluation in 1987 and development of a detailed restoration plan over 35 km of its length. Our analysis indicated that the steeper, more armored A and B channel types were more resistant to tie-drive effects. Lower-gradient meadow reaches (C channel types), however, were found to be 1.2 to 3.6 times wider than anticipated with minimal bank development, cover, pool quality, and habitat diversity. Carrying capacity estimates for trout were typically less than 30 kg/hectare in these impacted sections.

The habitat restoration plan for Douglas Creek focuses on increasing habitat diversity and cover in the short-term, and decreasing channel width and encouraging bank development in the long-term. A total of 176 treatments has been recommended, 90% of which are located in the 10.5 km of C channel. The most commonly recommended structures are tree revetments on meanders and log/tree funnels on straight sections. Construction is scheduled to begin in 1989.

Establishment and Propagation Techniques For Cottonwoods and Black Willows For Use in Southwestern Riparian Restoration

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Abstract.—As resource management agencies are planning for riparian vegetation rehabilitation projects, they are recognizing a constraint in the unavailability of locally adapted plant materials. In particularly short supply are native stands of young, rapidly growing saplings of cottonwood *Populus fremontii* and black willow *Salix gooddingii* and *Salix nigra* suitable for harvesting as 2.4 to 4.6-m dormant pole cuttings. These poles are used at riparian sites with water tables 1.2 to 2.4 m below the ground surface. Many other native tree and shrub species that are desired for reestablishment on damaged riparian sites are also not commercially available.

The Soil Conservation Service, Plant Materials Center, at Los Lunas, New Mexico, is working with cooperating agencies in the development of potentially superior ecotypes of native riparian plants. As one component of these activities, studies are being conducted on propagation techniques for cottonwood and black willow poles. The objective of these studies is to develop complete propagation systems that will be made available to cooperating agencies and commercial growers concurrently with the release of the superior ecotypes.

Our earliest propagation study used 45-50 cm cuttings of dormant wood that were divided into treatments of 10 to 14 d soak, 17 and 28 d in a mist chamber, and planting directly into the field. The study was duplicated a second year, and results confirmed that a 10 to 14 d soak yielded the highest rates of survival (40 to 50%).

In an effort to improve the survival of cuttings, additional studies were started in 1986 to determine the effect of length of cuttings, soaking period, and application of the root starter "Liquinox." A total of 120 cuttings each of 25, 37.5, 50, and 62.5 cm was taken from dormant Rio Grande cottonwood saplings and placed in cold storage. After 30 d, the cuttings were divided into four lots, each containing 25 cuttings/length group. One lot was soaked for 5 d in an "Liquinox" water bath, another lot in the same solution for 10 d. Remaining lots were soaked in water only for 5 and 10 d. The cuttings were planted in a split/split plot design, without replication.

Results indicated that survival of cuttings planted in fields receiving 5 cm, net application, of irrigation every 2 weeks was enhanced by a 10 to 14 d soak in water and by using cuttings of 50 to 62.5 cm in length (Table 1).

A third study was started in 1987 to determine the effects of length of cutting and water soaking on cuttings planted into production blocks where soil moisture was kept at full field capacity by frequent irrigation. Eighty cuttings each of 25, 37.5, and 50 cm were taken from a single accession of dormant Rio Grande cottonwood and placed into cold storage for 90 d. One half of the cuttings were soaked and the other half wrapped with slightly moistened sphagnum moss during the last 10 d of cold storage. Cuttings were planted in a replicated split plot design.

Results indicate that soaking did not significantly ($P \leq 0.05$) increase survival of 25 cm, 37.5 cm, and 50 cm cuttings under irrigation where soil moisture was maintained at field capacity (Table 2). As shown in previous studies, the longer cuttings had significantly ($P \leq 0.05$) higher survival.

Table 1.—Mean survival of four cutting lengths as affected by four treatments for 1986-1987.

Treatment method	Cutting lengths							
	25 cm		37.5 cm		50 cm		62.5 cm	
	1986	1987	1986	1987	1986	1987	1986	1987
5-d Soak without Liquinox	22	22	36	12	52	40	48	48
5-d Soak and Liquinox	24	24	0	4	4	4	16	16
10-d Soak without Liquinox	16	16	40	40	48	48	60	60
10-d Soak and Liquinox	16	16	32	28	44	44	56	52

Table 2.—The effect of cutting length treatments at two levels of preplanting soaking treatments on the survival of Rio Grande cottonwood cuttings.

Water Soaking Period	Percent Survival of Cuttings Per Plot			
	Cutting lengths cm			
	25	37.5	50	Mean
10 d	13	80	75	56
0 d	25	73	95	64

Least significant differences ($P \leq 0.05$) among cutting length means = 17.6.

Propagation increase blocks have been established using 1,000 each of candidate superior ecotypes of cottonwoods and three black willows. Soaked, nonrooted cuttings have been planted in furrows and flood irrigated. To produce the desired 2.4- to 4.6-m long poles in two growing seasons, attention in being given to maintaining adequate soil moisture, pruning, and control of weed competition. The application of preemergent herbicides during the preparation of planting fields has proven beneficial.

Pruning of some of the first and second year's growth in important in producing a tall, straight pole. After harvest of the first pole, pruning of the subsequent stump sprouts is essential to assuring production of poles over the next several years from that stump.

Our studies indicate that propagation techniques are available for large scale nursery production of 2.4- to 4.6-m long dormant poles of Rio Grande cottonwood and black willow. Intensive preplanting efforts, and diligent cultural practices are essential to the production of these long poles in two growing seasons.

Selection and Development of Plant Materials For Use in Southwest Riparian Zones

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Abstract.—The Los Lunas, New Mexico Plant Materials Center is one of 26 U. S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Plant Materials Centers (PMC) that are located throughout the USA, including Alaska and Hawaii. The purposes of PMCs are to assemble, test, and release plant materials for conservation use, determine techniques for their successful use, provide for their commercial increase, and promote the use of plant materials needed to meet the objectives and priorities of conservation programs.

For the purpose of controlling erosion and restoring wildlife and plant species diversity in riparian areas of New Mexico, the Los Lunas PMC, in cooperation with the Bureau of Reclamation (BOR), is assembling, testing, developing methods of establishment and future releasing for commercial production superior strains of Rio Grande cottonwood *Populus fremontii* and black willow *Salix gooddingii* and *Salix nigra*.

Non-irrigated pole cutting establishment trials of Rio Grande cottonwood and black willow were initiated in 1980. Trials were performed mainly in soil lycimeters where the water table was controlled and in field plantings. Results of these trials indicated that for best survival in non-irrigated field plantings the pole cuttings should be augured to the depth of the lowest anticipated water table.

Collection of Rio Grande cottonwood and black willow accessions in the Rio Grande valley began in 1983. The PMC is searching for ecotypes that have superior qualities in growth rate, longevity, and competitive abilities and adapt to a broad range of habitat types.

Thirty-nine of the best accessions of Rio Grande cottonwood and black willow were installed in a randomized replicated block planting at the Los Lunas PMC in 1984. By 1987, five superior Rio Grand cottonwood and three black willow were selected. The selected cottonwood accessions, after four growing seasons, averaged 75% survival, 7.9 m in canopy height, and 3.7 m in canopy width. The selected black willow accessions, after four growing seasons, averaged 80% survival, 4.3 m in canopy height, and 2.4 m in canopy width. These selections were further tested at off-center locations in New Mexico, including Bernardo, Artesia, Bosque del Apache Wildlife Refuge, and Percha Field (approximately 32.3 km south of Truth or Consequences, New Mexico). Mean survival at the five locations among accessions ranged from 13% to 80%.

One thousand tree increase blocks were established of each selected accession at the Los Lunas PMC in 1988. These selections and future selections will be tested in riparian areas throughout New Mexico to determine the adaptation range of each ecotype.

In 1988, building on the accomplishments of the BOR/Los Lunas PMC effort, an interagency riparian agreement was initiated between the Los Lunas PMC and U. S. Bureau of Reclamation, New Mexico Department of Game and Fish, U. S. Fish and Wildlife Service, Bosque del Apache National Wildlife Refuge, U. S. Bureau of Land Management, and the Army Corps of Engineers. The riparian effort will be expanded to include all plant species suitable for use in riparian habitats in the southwest, development of propagation and establishment techniques, and raising of nursery stock to provide the agencies with the requested plant material of experimental accessions prior to commercial release. Plant species currently under study in addition to Rio Grande cottonwood and black willow include: coyote willow *Salix exigua*, Anderson wolfberry *Lycium andersonii*, Tornillo *Prosopis pybescus*, buffaloberry *Sheperdia canadensis*, plains cottonwood *Populus sargentii*, narrowleaf cottonwood *Populus angustifolia*, and peachleaf willow *Salix amygdaloides andress*.

Conversion Table

Metric measurements are used throughout this document. To convert metric to English, use the information below.

Centimeters × 0.3937 = inches

Hectares × 2.471 = acres

Kilograms × 2.205 = pounds

Kilometers × 3,281 = feet

Kilometers × 0.6214 = miles (statute)

Meters × 3.281 = feet

Cubic Meters × 264.2 = gallons

Cubic Meters × 35.31 = cubic feet

Millimeters × .039 = inches

°C × 1.8 + 32 = °F

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